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ADAPTATION OF SAP IV COMPUTER CODE TO AIRCRAFT SHELTER ANALYSIS PROGRAM

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This report is concerned with the adaptation of a linear, static and dynamic structural analysis computer code (SAP IV) to aircraft shelter structural components.

A number of features were added to the documented version of SAP IV to decrease the time and effort necessary to set up practical problems. The Free Format Input Program enables the user to input data without the confusing and restrictive format rules of the original version. To aid in finding errors in element layout, a versatile mesh plot package has been included. A (Cont'd)

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stress/displacement versus time plot capability now enables the user to generate report quality output time histories. A specific procedure for approximating the nonlinear behavior of cracked concrete has been developed and is included in this report.

Although SAP IV is designed to treat a large number of different types of elements, this study was directed specifically at three element types; thin shell or plate, thick shell or plate, and beam. These elements were considered as most applicable to the aircraft shelter problem. The FFIP and mesh plotting routines are applicable only to these three elements, while the time-history plotting capability will function with all the elements presently in SAP IV.

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PREFACE

This report was prepared by the Civil Engineering Research Facility, University of New Mexico, Albuquerque, New Mexico, under contract F29601-76-C-0015, Job Order 00DE4020. The work effort was an Investigational Engineering project sponsored by HQ Air Force, Directorate of Engineering and Services and managed by the Air Force Civil Engineering Center, Tyndall Air Force Base, Florida.

This report summarizes work done between November 1975 and June 1976. Captain Dennis Morrison was the project officer.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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TABLE OF CONTENTS

LIST OF FIGURES

SECTION I

ADAPTION OF THE SAP IV[1] COMPUTER CODE TO THE AIRCRAFT SHELTER ANALYSIS PROGRAM

INTRODUCTION

1. GENERAL BACKGROUND

The United States Air Force must continually develop and improve shelters and shelter systems for the protection of aircraft. These protective facilities must function satisfactorily under a number of external environments, the worst of which is weapon-induced structural loading. Efficient design and evaluation of protective shelters for a variety of static and dynamic loads necessitates use of advanced computer techniques. Such computer analyses must be capable of determining the linear response of structures with geometrical configurations typical of aircraft shelter components.

2. OBJECTIVE AND SCOPE OF STUDY

This study was to select an existing computer code based upon the finite element method of structural analysis and to revise this code to enable the Air Force to effectively analyze shelter development. The ability of the code to predict the linear response of shell and folded plate structures subjected to arbitrary static and dynamic loading conditions was of primary importance.

The scope of this effort as outlined in the technical directive was limited to the modification of an existing computer program to obtain a code with the following characteristics:

Elements to be included in the finite element approach:

a. A plate finite element.

b. A shallow or semi-thick shell finite element.

c. Beam-columns and plate or shell stiffeners.

1. Bathe, K. J.; Wilson, E. D.; Peterson, F. E., SAP IV - A STRUCTURAL ANALYSIS PROGRAM FOR STATIC AND DYNAMIC RESPONSE OF LINEAR SYSTEMS, Earthquake Engineering Research Center, Report No. EERC-73-11, June 1973, Revised April 1974, College of Engineering, Berkeley, California.

Materials to be modeled (treated as linearly elastic):

a. Reinforced concrete (cracked or uncracked).

b. Plain concrete.

c. Structural steel (including cold rolled corrugated steel).

The nodal boundary restraint options:

a. Axial.

b. Lateral.

c. Moment resisting.

d. Variable torsional stiffness (i.e., end wall simulation).

Typical input parameters (free format preferred):

a. Geometrical shape.

b. Material properties.

c. Static loading conditions.

d. Dynamic load versus histories.

e. Output control indicators.

Output data:

a. Displacements.

b. Reactions at boundaries.

c. Stress/strain.

d. Principal stress/strain.

e. Displacement/stress versus time histories.

A plot capability of input and output data was required.

Although some portions of the code were rewritten, the purpose was not to develop a completely new algorithm or program, or to test physical models. The effort was limited to analytical modeling.

The approach to the modification of the code was as follows:

a. A hierarchy of problems to be sequentially addressed and solved by the computer code while the final code was being developed was formulated and submitted for approval.

b. Concurrently, existing codes were reviewed and a code was selected based on technical requirements of this project.

c. The selected code was modified as necessary and the selected problems were solved by using the revised code.

This report describes the formulation of the program and validation of the analytical technique.

SECTION II

SELECTION AND USE OF A COMPUTER CODE

1. SELECTION OF A COMPUTER CODE

Several computer codes incorporating many of the features required for this project were considered. Codes such as ANSYS and MARC were quickly eliminated because they contained the ability to handle nonlinear material and geometric relations which was not required. In addition, these codes have proprietary restrictions which render them unavailable for scrutiny and modifications. The proprietary restraint also applies to STARDYNE, which otherwise would have been an excellent possibility. Other codes were rejected because of insufficient documentation or lack of verification.

Two codes, NASTRAN[2] and SAP IV, were reviewed in some detail. It was recommended that SAP IV be adopted as the basic source code for the following reasons:

a. The code contained a large number of features which fulfilled technical requirements of the project.

b. The code had been used for a sufficient period of time to detect and correct the major errors. On the other hand, the code does contain some of the latest advances in finite element theory and time integration schemes.

c. The code is documented, open, and available for modifications.

d. NASTRAN also contains many of the same capabilities as SAP IV, but it permits nonlinear analyses. This latter feature greatly adds to the complexity of the code, making it more difficult to modify. Also, the generalized nature of NASTRAN results in the need for more computer time and storage than that required for the same problem run with the use of SAP IV.

2. THE USE OF SAP IV

A version of SAP IV prepared by Wright Patterson AFB was obtained and installed, and initial problems were run with very little difficulty. Other than the usual problems associated with interpreting

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2. NASA SP-223, THE NASTRAN PROGRAMMER'S MANUAL, Douglas, F., Editor, National Aeronautics and Space Administration, Washington, D. C. 1970.

statements in a user's manual, no difficulties were encountered. The code performed efficiently and the results compared quite favorably with classical results for certain specific test problems. Furthermore, on the basis of numerical experimentation, it was found that the modal solution technique for dynamic problems appeared to be much more efficient than the direct integration method.

A set of illustrative problems was chosen to exercise the various features of SAP IV that were of primary interest in this study. In particular, the static and dynamic integration routines were to be used on problems utilizing beam, plate, and thick shell elements only. The complexity of these problems ranged from simple beams and plates to structures such as aircraft shelters and doors. The description of the problems, together with selected results, is given in a later section.

When SAP IV was chosen, it was clear that certain modifications and additions would be necessary to meet the technical requirements of this project. Additional items became apparent with the effort associated with obtaining solutions to the set of illustrative problems. The tasks that had to be addressed consisted of the following:

a. Since SAP IV is based entirely on linear theory, a systematic approach for analyzing reinforced or plain concrete members was not contained in the SAP IV User's Manual. A procedure for computing equivalent properties for concrete beams, plates, or shells was required.

b. The input format for SAP IV is very rigid with such anomalies as blank cards from time to time to denote zero values, the end of a section of input data, and problem termination. For the beginning user, such rules can be very time consuming. Consequently, the need for a free format input program was quite evident.

c. SAP IV did not contain a subroutine for computing principal stresses and strains. This subroutine is a desirable feature for determining the possibility of failure.

d. SAP IV did not contain a mesh plot routine, making the verification of input geometrical data extremely difficult. Frequently, for very large problems, the only method is to use engineering judgment on the nature of the results to a specific loading function. For dynamic problems this is a very risky approach. Thus, the addition of the capability for plotting mesh points was assigned a very high priority.

e. The output of SAP IV consists entirely of numerical values and plots constructed on the printer. For dynamic problems, such data can be overwhelming and difficult to interpret. The need for a time history plotting package then became evident.

f. The use of the SAP IV modal solution technique for dynamic problems frequently resulted in the diagnosis that the storage limit was exceeded. Apparent reason for this is that the generalized force vector is computed for all time steps before the modal equations are integrated. Consequently, any limitation on computer memory allocation also limits the number of time steps, or the duration of time for which a solution can be obtained.

g. It was discovered that a limited number of generalized displacements could be requested in output. This appears to be a flaw within SAP IV and should not be a major one since there is no similar limitation on generalized stresses.

Some of these limitations were expected; others were not and significant effort was required to verify that these problems were associated with the code and not the input data. Because of the limited time available to complete the project, the highest priority was placed on items a, b, d, and e with the other items to be considered only if time became available. The results of this part of the project are presented in the next section.

SECTION III

ADDITIONS TO THE PROGRAM

1. EQUIVALENT STIFFNESS PARAMETERS FOR CONCRETE SECTIONS

Many aircraft shelters and other structures of interest to the Air Force are made of concrete or reinforced concrete. Since such structural members are designed to crack under highly probable loading conditions, an analysis must reflect this nonlinear behavior in some fashion. If a code (such as SAP IV) based on linear theory is to be used, properties for these structural members must be chosen so that the actual nonlinear behavior is approximated or averaged in some sense.

If a procedure can be established for beams, then the extension to plates and thick shells is relatively straightforward. The procedure used for obtaining an equivalent bending stiffness of a beam can be applied directly to orthotropic plates by using the beam formulas in each of the principal material directions. There is a factor $1-\nu^2$(ν is Poisson's ratio) that is not present in beam theory. However, in light of the assumptions made in arriving at an equivalent linear stiffness, the incorporation of such a term is not difficult.

The use of the thick or thin shell element in SAP IV introduces additional complications in that actual elastic constants rather than bending stiffnesses must be satisfied. Because bending is the dominant mode of deformation for most engineering structures, it is imperative that the resultant bending stiffness correspond closely to that of the actual structural element. A convenient way of achieving this correspondence is to choose the appropriate elastic constants for concrete and then select values for the thickness and mass density so that the resultant bending stiffness and mass per unit shell reference area are equal to the experimentally or analytically determined values for that particular section. If a different bending stiffness exists in the direction normal to that already modeled, the selection of appropriate orthotropic elastic material properties in the element can be used to approximate the different stiffness.

The basis for equivalent plate and thick shell element properties is contained in the assumptions used for beams. Thus, the remainder of this subsection is devoted to beams with several illustrative examples. Extensions to plates and thick shells are considered to be rather straightforward and are only included in the sample problems.

When reinforced concrete members deform under the action of some load, cracking of the concrete occurs on the tensile side of the member. This highly nonlinear behavior must be approximated with an appropriate linear property if a linear elastic analysis is to be used with any degree of accuracy.

Unsymmetrical sections introduce another complicating factor in that the cracked stiffness for both directions of bending may be different. As a reasonable approximation for problems in which any one section may experience both positive and negative bending moments, it is proposed that an additional averaging procedure be used. First, obtain the average stiffnesses of the cracked and uncracked sections for bending in both directions. Then use the average of these two stiffnesses to obtain a resultant linear equivalent stiffness to be used in a dynamic analysis.

The approximate formula suggested by Biggs[3] for the average bending stiffness of rectangular sections is

$$E_c I_B = \frac{E_c b d^3}{2} (5.5\rho_s + 0.083)$$

in which

E_c = Young's modulus for concrete,

I_B = average second area moment,

b = width of the member,

d = effective depth of the member, and

ρ_s = steel ratio.

Since it is not clear just what assumptions were used in deriving this equation, it is proposed that first principles be used in obtaining average stiffness parameters. The following examples illustrate the procedure, and Biggs' formula is used for comparison.

Example 1. Symmetric Section.

Consider a rectangular beam (Figure 1) with the same reinforcing top and bottom so that the average stiffness is the same for both positive and negative bending.

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3. Biggs, J. M., Introduction to Structural Dynamics, McGraw Hill Book Co., New York, N. Y., 1964.

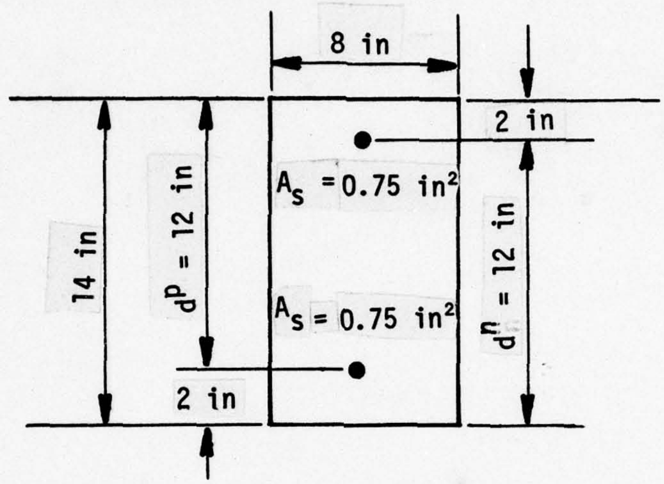


Figure 1. Symmetric Rectangular Section

Area of steel, top and bottom, $A_s^t \approx A_s^b = 0.75\ \text{in}^2$ with distances $d^p = d^n = 12$ in. The steel ratio is, by definition,

$$\rho_s = \frac{A_s^t + A_s^b}{(8\ \text{in})(12\ \text{in})} = 0.0156$$

Young's modulus for concrete is given by

$$E_c = (w)^{1.5}\ 33\sqrt{f_c'}$$

in which w is the weight density in lb/ft³ and f_c' is the concrete strength in psi. For 4000 psi concrete

$$E_c = (145)^{1.5}(33)\sqrt{4000} = 3.64 \times 10^6\ \text{psi}$$

The ratio of steel to concrete Young's moduli is

$$n = E_s/E_c = \frac{29 \times 10^6 \text{ psi}}{3.64 \times 10^6 \text{ psi}} = 8.0$$

Thus the steel area is transformed to an effective concrete area 8 times as large. For the uncracked section (Figure 2) the moment of inertia becomes

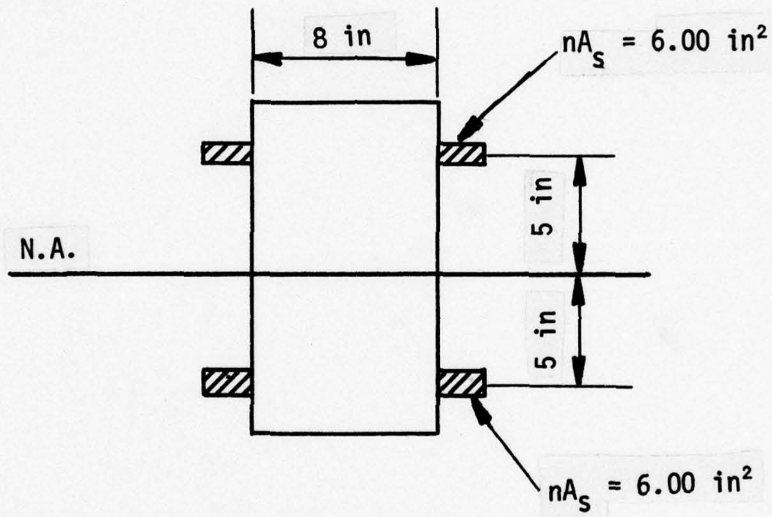


Figure 2. Transformed Uncracked Section

$$I^u_{N.A.} = \frac{1}{12} bh^3 + 2nA_s(5 \text{ in})^2 = \frac{1}{12}(8)(14)^3 + 2(6 \text{ in}^2)(25 \text{ in}^2) = 2129 \text{ in}^4$$

For the cracked section (Figure 3), the location of the neutral axis must be determined first. Let the neutral axis be $\bar{y}$ from the upper surface.

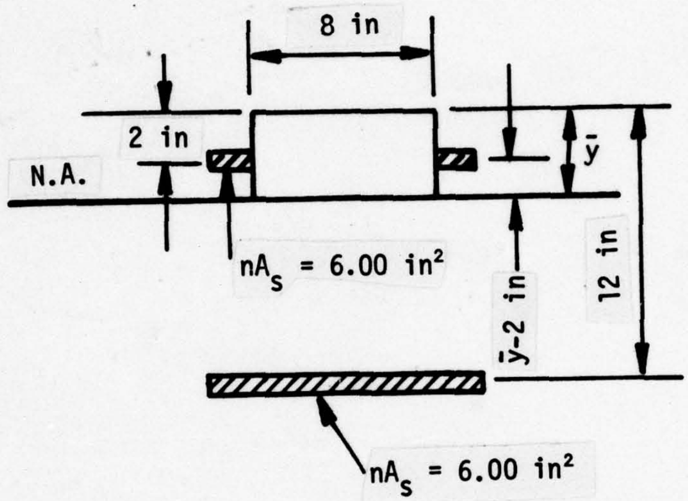


Figure 3. Transformed Cracked Section

The total equivalent concrete area is

$$\bar{A} = 8\bar{y} + 12$$

Then first moments about the top surface yield

$$\bar{y}\bar{A} = \frac{(\bar{y})^2}{2}(8\text{ in}) + (6\text{ in}^2)(2\text{ in}) + (6\text{ in}^2)(12\text{ in})$$

and the solution is

$$\bar{y} = 3.32\text{ in}$$

Now, the second area moment about the neutral axis for the cracked section is

$$I^{c}_{N.A.} = (1/3)8\text{ in }(3.32\text{ in})^3 + 6\text{ in}^2(3.32\text{ in} - 2\text{ in})^2$$

$$+6\text{ in}^2(12\text{ in} - 3.32)^2 = 560\text{ in}^4$$

The average second area moment of the cracked and the uncracked section is

$$I_a = \frac{2129\text{ in}^4 + 560\text{ in}^4}{2} = 1345\text{ in}^4$$

The value obtained from Biggs is

$$I_B = \frac{bd^3}{2}(5.5\rho_s + 0.083) = \frac{(8\text{ in})(12\text{ in})^3}{2}\{5.5(0.0156) + 0.083\} = 1168\text{ in}^4$$

For the purpose of comparison

$$\frac{I_a}{I_B} = 1.15$$

Example 2. Unsymmetric Reinforcing

Consider a rectangular beam with different reinforcing at the top and bottom.

In Figure 1, let

$$A^t_s = 0.5\text{ in}^2$$

$$A^b_s = 1.25\text{ in}^2$$

$$d^t = d^b = 12\text{ in}$$

The steel ratio for the cross section is

$$\rho_s = \frac{(0.5)+(1.25)}{(8)(12)} = 0.0182$$

The transformed uncracked section is illustrated in Figure 4.

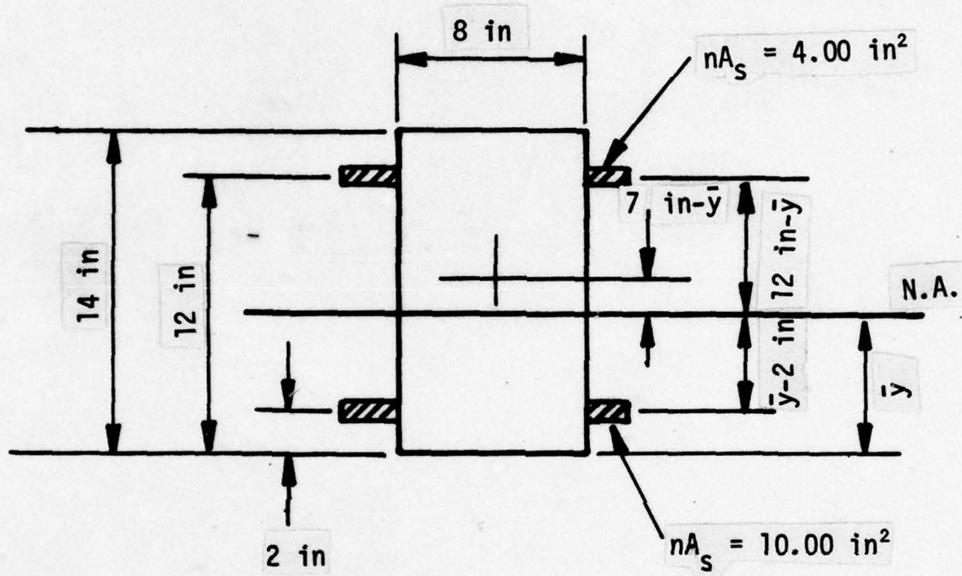


Figure 4. Transformed Uncracked Section

Total equivalent concrete area

$$\bar{A} = (8)(14)+4.0+10.0 = 126 \text{ in}^2$$

The distance from the bottom face to the neutral axis is $\bar{y}$ where

$$\bar{y}\bar{A} = (112)(7)+(4.0)(12)+(10)(2) = 852 \text{ in}^3$$

$$\bar{y} = 6.76 \text{ in}$$

The second area moment about the neutral axis is

$$I^u_{N.A.} = \frac{1}{12}(8)(14)^3+(8)(14)(7-6.76)^2+4.00(12-6.76)^2+10(4.76)^2 = 2172 \text{ in}^4$$

The transformed cracked section for positive bending is shown in Figure 5.

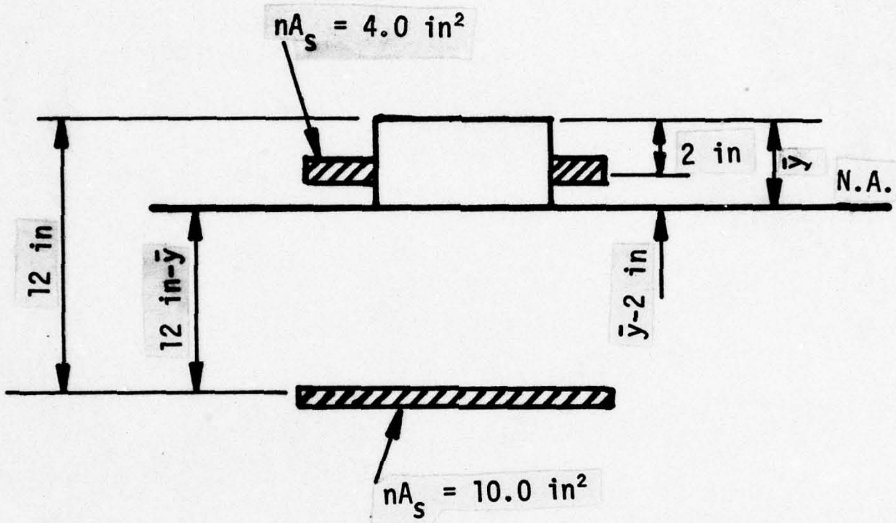


Figure 5. Transformed Cracked Section for Positive Bending

The total equivalent concrete area is

$$\bar{A} = (8)(\bar{y})+(4)+(10) = (8\bar{y}+14)\ in^2$$

The location of the neutral axis with reference to the top face is obtained from

$$\bar{y}\bar{A} = \frac{\bar{y}}{2}(8\bar{y}) + (2)(4) + (12)(10) = 4\bar{y}^2 + 128$$

or

$$4\bar{y}^2 + 14\bar{y} - 128 = 0$$

$$\bar{y} = 4.17\ in$$

and

$$I^C_{N.A.} = \frac{1}{3}(8)(4.17)^3 + 4(4.17-2)^2 + 10(12-4.17)^2 = 825\ in^4$$

The average value for the second area moment for positive bending becomes

$$I_a^p = \frac{1}{2}(2172+825) = 1499 \text{ in}^4$$

The transformed cracked section for negative bending is shown in Figure 6.

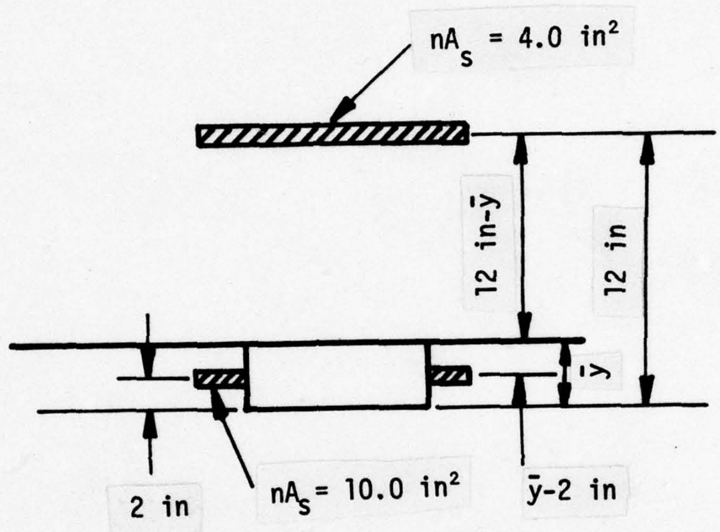


Figure 6. Transformed Cracked Section for Negative Bending

The total equivalent concrete area is

$$\bar{A} = 8\bar{y}+(4)+10 = (8\bar{y}+14) \text{ in}^2$$

With reference to the bottom face, the location of the neutral axis is given by

$$\bar{y}\bar{A} = \frac{\bar{y}}{2}(8\bar{y})+(2)(10)+(12)(4) = 4\bar{y}^2+68$$

or

$$4\bar{y}^2+14\bar{y}-68 = 0$$

$$\bar{y} = 2.73 \text{ in}$$

and

$$I_{N.A.}^c = \frac{1}{3}(8)(2.73)^3+10(2.73-2)^2+4(12-2.73)^2 = 403 \text{ in}^4$$

The average value for the second area moment for negative bending is

$$I_a^N = \frac{1}{2}(403+2172) = 1288 \text{ in}^4$$

The average value for both positive and negative bending is then

$$I_a = \frac{1}{2}(I_a^p+I_a^N) = 1394 \text{ in}^4$$

Biggs' formula yields

$$I_B = \frac{bd^3}{2}\,5.5\rho_s+0.083 = \frac{(8)(12)^3}{2}\{5.5(0.0182)+0.083\} = 1266 \text{ in}^4$$

and

$$\frac{I_a}{I_B} = 1.10$$

Example 3. Unsymmetrical Cross-section with Reinforcing

The following cross-section (Figure 7) has been suggested as a suitable model for a section of corrugated material from an aircraft shelter.

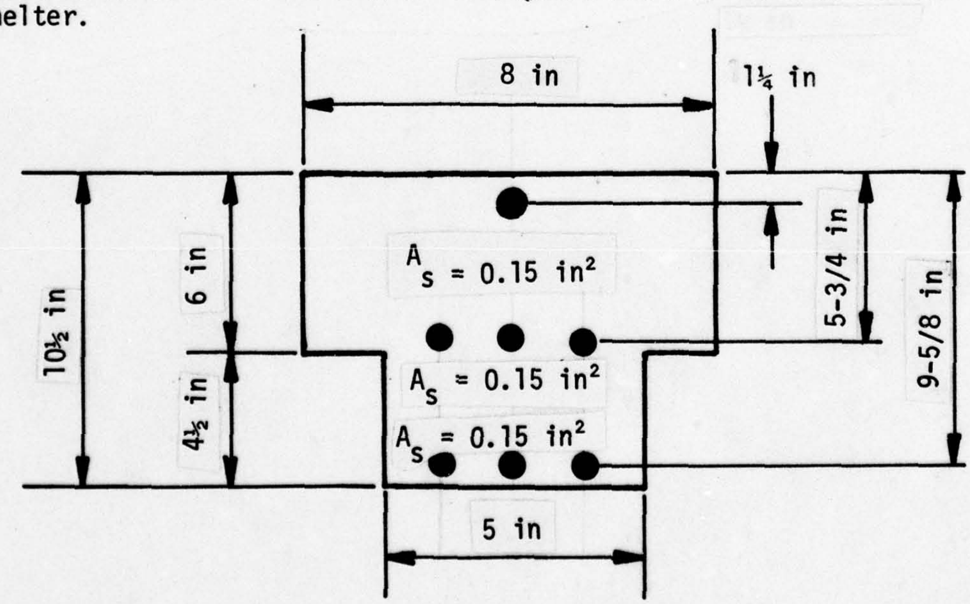


Figure 7. Unsymmetrical Cross-section

With

$$f'_c = 5000$$

it follows that

$$E_c = 4.07 \times 10^6 \text{ psi}$$

$$n = E_s/E_c = 29/4.07 = 7.13$$

The transformed uncracked section is shown in Figure 8. The equivalent concrete area is

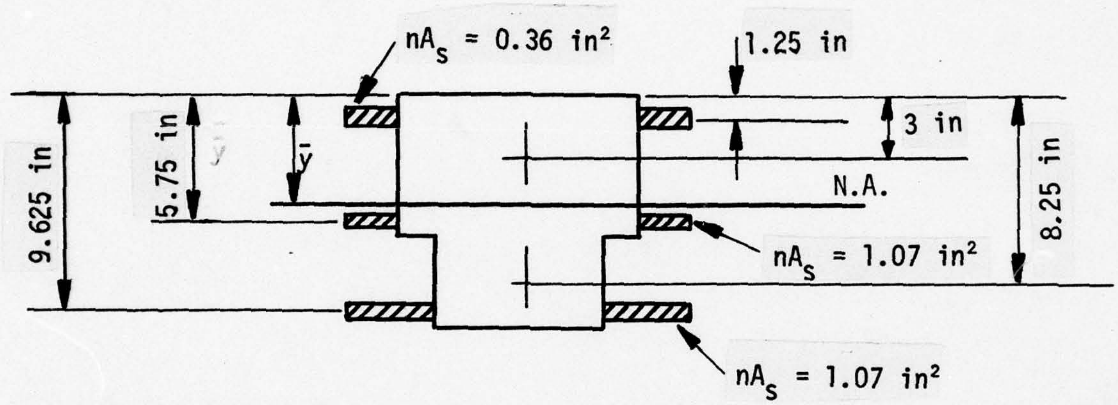


Figure 8. Transformed Uncracked Section

$$\bar{A} = (6)(8)+(5)(4.5)+(2)(1.07)+0.36 = 73.0 \text{ in}^2$$

and taking moments about the top face, the location of the neutral axis is given by

$$\bar{y}\bar{A} = (0.36)(1.25)+(48)(3)+(1.07)(5.75)+(22.5)(8.25)+(1.07)(9.625) = 346.5 \text{ in}^3$$

$$\bar{y} = 4.75 \text{ in}$$

The second area moment is

$$I^u_{N.A.} = \frac{1}{12}8(6)^3+48(4.75-3)^2+\frac{1}{12}(5)(4.5)^3+(22.5)(2.25+1.25)^2$$
$$+(0.36)(3.5)^2+(1.07)(5.75-4.75)^2+(1.07)(5.75-0.875)^2$$
$$= 636 \text{ in}^4$$

Under positive bending, the transformed section is shown in Figure 9. The equivalent concrete area is

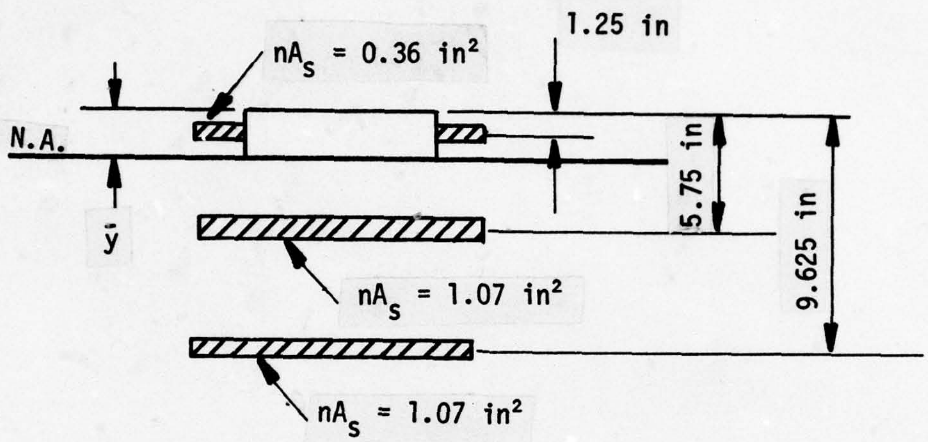


Figure 9. Transformed Cracked Section for Positive Bending

$$\bar{A} = 8\bar{y}+0.36+1.07+1.07 = (8\bar{y}+2.50)\ in^2$$

and taking moments about the top face the neutral axis is obtained from

$$\bar{y}\bar{A} = (8\bar{y})(\frac{\bar{y}}{2})+(0.36)(1.25)+(1.07)(5.75)+(1.07)(9.625) = 4\bar{y}^2+16.9$$

or

$$4\bar{y}^2+2.50\bar{y}-16.9 = 0$$

and

$$\bar{y} = 1.77\ in$$

The second area moment is

$$I^c_{N.A.} = \frac{1}{3}(8)(1.77)^3 + (0.36)(1.77-1.25)^2 + (1.07)(5.75-1.77)^2$$
$$+ (1.07)(9.625-1.77)^2 = 98 \text{ in}^4$$

The average value for positive bending is

$$I^p_a = \tfrac{1}{2}(636+98) = 367 \text{ in}^4$$

The transformed cracked section for negative bending is shown in Figure 10.

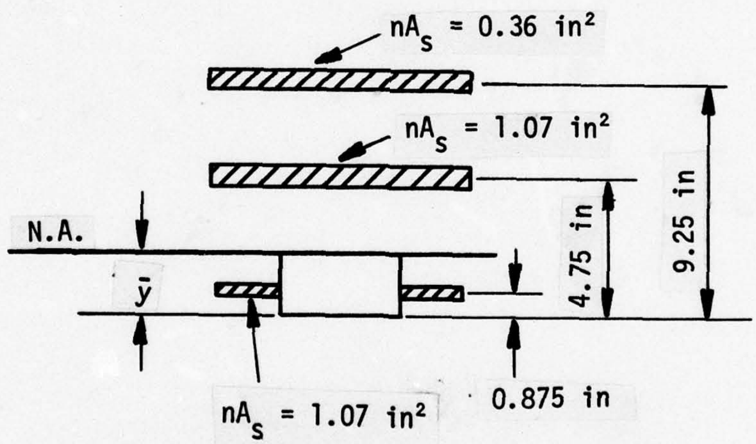


Figure 10. Transformed Cracked Section for Negative Bending

The equivalent concrete area is

$$\bar{A} = (5\bar{y}+2.50) \text{ in}^2$$

and the location of the neutral axis is obtained by taking moments about the bottom face

$$\bar{y}\bar{A} = 5\bar{y}\left(\frac{\bar{y}}{2}\right)+(1.07)(0.875)+(1.07)(4.75)+(0.36)(9.25) = 2.5\bar{y}^2+9.35$$

or

$$2.5\bar{y}^2+2.50\bar{y}-9.35 = 0$$

and

$$\bar{y} = 1.50 \text{ in}$$

The second area moment is

$$I^{C}_{N.A.} = \frac{1}{3}(5)(1.50)^3+(1.07)(1.50-0.875)^2+(1.07)(4.75-1.50)^2$$

$$+(0.36)(9.25-1.50)^2 = 39 \text{ in}^4$$

The average value for negative bending is

$$I^N_a = \tfrac{1}{2}(636+39) = 337 \text{ in}^4$$

For both positive and negative bending, the recommended value is

$$I_a = \tfrac{1}{2}(I^P_a+I^N_a) = 352 \text{ in}^4$$

Biggs does not suggest a procedure for a section as complicated as this one. However, his approach could be adapted as follows: The steel cross section area is $A_s = 0.05+0.15+0.15 = 0.35$ in^2. For positive bending use b=8 in and d=9.625 in. Then

$$I^P_B = \frac{bd^3}{2}\{5.5\rho_s+0.083\} = (8)\frac{(9.625)^3}{2}\{5.5\frac{(0.35)}{(8)(9.625)}+0.083\} = 385 \text{ in}^4$$

For negative bending use b = 5 in and d = 9.25 in

Then

$$I^N_B = (5)\frac{(9.25)^3}{2}\{5.5\frac{(0.35)}{(5)(9.25)}+0.083\} = 247 \text{ in}^4$$

The average of the two values is

$$I_B = \tfrac{1}{2}(385+247) = 316 \text{ in}^4$$

and

$$\frac{I_a}{I_B} = 1.11$$

For the three beam sections presented, the beam stiffnesses calculated by averaging four stiffnesses (cracked and uncracked for positive bending and cracked and uncracked for negative bending) are from 10 percent to 15 percent greater than those determined from the Biggs formula. The Biggs formula is not directly applicable to non-rectangular sections, and for complicated sections its use becomes highly questionable. For simple cross-section, however, its use in determining dynamic bending stiffnesses can be justified from the foregoing test calculations. For complicated beam cross-sections, although parameters may be chosen so that the Biggs formula stiffness compares well with the four stiffness average method, it is suggested that only the latter method be used in determining the dynamic stiffness.

2. FREE FORMAT INPUT PROGRAM

To alleviate the time consuming and confusing format rules for introducing data into the SAP IV code, a program known as FFIP was developed. FFIP, short for Free-Format Input Program, enables the user to prepare input data for SAP IV with considerable ease and speed and to avoid the rigidity in form necessary for creating input data directly applicable to the SAP IV program. Ultimately, input data, when properly prepared, can be completely shuffled, and the resultant output of FFIP will be identical every time. FFIP is a separate, independent program to be run just before executing the SAP IV program in a single job run, and it creates a resultant output tile, Tape 1, which is to be used as input to the SAP IV program. To utilize FFIP proficiently, the user is required only to be familiar with FFIP input syntax rules, which are simple and straightforward, and FFIP keyword parameters. Explanations of FFIP input requirements and further elaborations of FFIP characteristics are available in Appendix A.

3. GRAPHICS PLOT PACKAGES

Two plotting packages were developed for the SAP IV code to simplify both data input and output. For dynamic problems the time history package provides the user with plots of displacement or stress versus time. The mesh plot package permits rapid verification of input geometrical data.

3.1 Time History Plot Package

A time history plot package is available for the user who wishes to analyze voluminous SAP IV output with ease and efficiency. The plot package has been included in SAP IV without major modification to the code and the standard software package is required for its execution. Plots can be created by requesting printer plot from SAP IV (i.e., KKK=2) with data for specific component members. No other input data are required and each resultant plot contains a maximum of three curves which are automatically grouped depending on component members specified. A normalization factor is provided for minima and maxima of all three curves when applicable. Also, the beginning and ending time data points are automatically plotted to the extrema. Each curve permits up to 100 points. If there are more than 100 points, the data will be incremented. Further elaborations, including samples and functional descriptions of the program are given in Appendix B.

3.2 Mesh Plot Package

A mesh plot package is available for rapid and simple verification of input geometric data. It is a separate program which can only be run after a successful execution of SAP IV in a single job run. In addition to the normal input data to the SAP IV program, a variable named MODEX in the master control card section of the SAP IV manual must be set to 1. SAP IV, subsequently, produces an output file, Tape 8, which provides one of the required inputs to the mesh program. Besides TAPE 8, card input must include data, such as visual orientations of generated object defined in 3-D space and selections of optional node and element labelings and various or all elements to be plotted. Card input is again in free-format and is easy to use. Explanations of syntax rules, a list of keyword parameters and further details of mesh plot characteristics are available in Appendix C.

SECTION IV

PROBLEMS THAT DEMONSTRATE THE APPLICABILITY OF SAP IV TO AIRCRAFT SHELTER ANALYSIS

1. BACKGROUND

A hierarchy of problems was selected to illustrate the use of SAP IV for obtaining solutions in cases that ranged from the most elementary type to those that were fairly complex and representative of the type that might be encountered in a detailed analysis of an aircraft shelter. The simpler problems were chosen to demonstrate basic features of the code and to allow comparison with solutions obtained from strength of materials formulas. The more complex problems were designed to represent the structures and load environments actually encountered in Air Force design and experiments. Since the objective of this part of the study was to determine the appropriateness of SAP IV for this class of problems, no attempt was made to perform the kind of detailed analysis that might be required under a given situation.

Of the large number of elements available in SAP IV, the following problems were solved using only beam, thin shell or plate, and thick shell or plate elements. Input for each problem was introduced into the code using the Free Format Input Program (see Appendix A). The mesh plots and time history plots have been selected so that over the range of problems considered, most of the options available with the plot package are exercised.

2. CANTILEVER BEAM

2.1 Static Analysis Under Five Different Loads (Figure 11)

2.1.1 Problem Description

A 25-foot long cantilevered W 12 x 40 beam was subjected to the following concentrated loads acting on the free end of the beam:

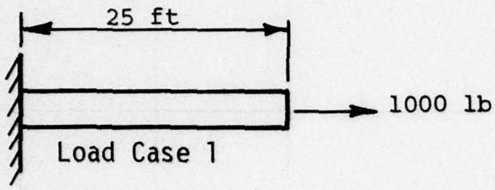
a. 1000-lb axial load

b. 1000-lb vertical load

c. 300,000-in-lb moment

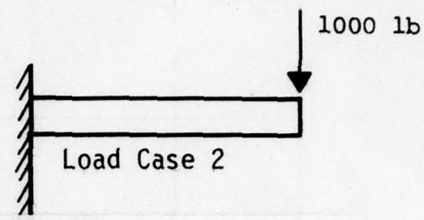
d. 5000-in-lb torque

e. All of the above



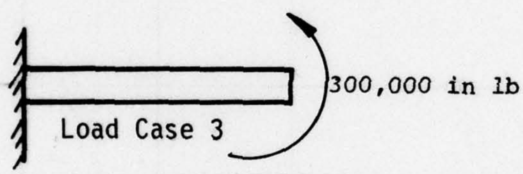
THEORY $\Delta_x = 9.4044 \times 10^{-4}$ in

SAP IV $\Delta_x = 9.4044 \times 10^{-4}$ in
NODE 6



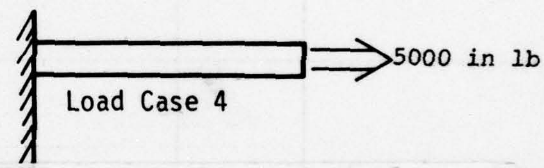
THEORY $\Delta_y = -1.0011$ in

SAP IV $\Delta_y = -1.0088$ in
NODE 6



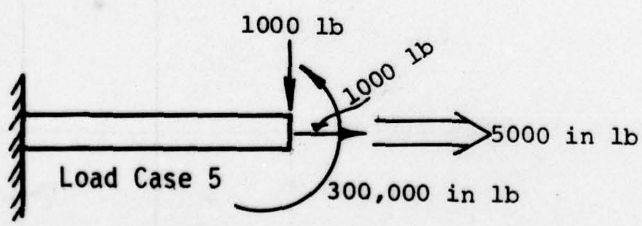
THEORY $\Delta_y = 1.5017$ in

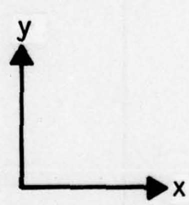
SAP IV $\Delta_y = 1.5017$ in
NODE 6



THEORY x-rotation = -0.14067 radians

SAP IV x-rotation = -0.14067 radians
NODE 6





THEORY $\Delta_y = 0.5006$ in

SAP IV $\Delta_y = 0.4929$ in
NODE 6

Figure 11. Cantilever Beam Load Cases

2.1.2 Five 3-D beam elements were used in the analysis. The assignment of nodes and beam elements is shown in Figure 12.

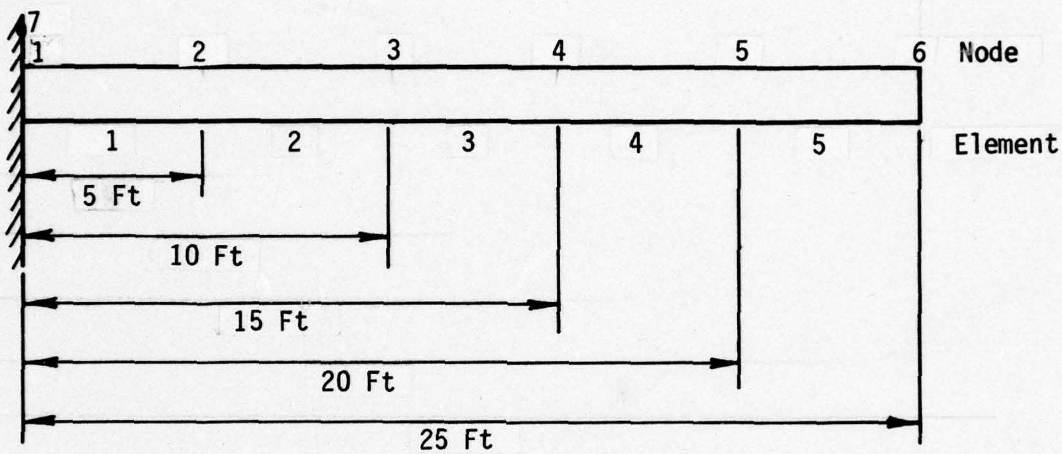


Figure 12. Cantilever Beam Element Assignment

2.1.3 Input Data - Five Load Cases

```
HEADER=*STATIC ANAL. CONC. LOADS CANT. BEAM
NUMNP=7,NELTYP=1,LL=5
IX(1,7)=1,1,1,1,1,1
IX(2 6)=0,0,1,0,1,0,
XYZT(1)=0.,0.,0.,0.,
XYZT(2)=60.,0.,0.,0.,
XYZT(6)=300.,0.,0.,0.,
XYZT(7)=0.,60.,
NBEAM=5,BNEPC=1,BNMPC=1,
BMPC(1)=2.9E7,0.3,7.339E-4,.289
BEPC(1)=11.,3.51,4.128,.956,44.1,310.,
BEAM(1)=1,2,7,1,1,
BEAM(5)=5,6,7,1,1,
CLMD(6,1)=1000.,
CLMD(6,2)=0.,-1000.,
CLMD(6,3)=,,,,,3.0E5,
CLMD(6,4)=,,,5.0E3
CLMD(6,5)=1000.,-1000.,,5.0E3,,3.0E5
'
```

2.1.4 Results

A comparison of deflections as computed by SAP IV and a standard strength of material approach was made for each of the five load cases. The maximum difference in computed deflections was 1.56 percent, and this can probably be attributed to the fact that deflections computed using strength of materials did not take shear deformations into account, whereas, SAP IV did. Because the problem analyzed was statically determinate, no appreciable differences in shears and moments were computed by either approach.

Load Case 1 (1000 lb axial) X-translation

SAP IV - node 6 $\Delta_x = 9.4044 \times 10^{-4}$ in

Strength of Materials $\Delta = P\ell/AE = (1000\ \text{lb})\dfrac{(300\ \text{in})}{11.0\ \text{in}^2(29 \times 10^6\text{psi})}$

$= 9.4044 \times 10^{-4}$ in

Load Case 2 (1000 lb vertical) y-translation

SAP IV - node 6 $\Delta_y = -1.0088$ in

Strength of Materials $\Delta_y = \dfrac{Pl^3}{3EI} = (1000\ \text{lb})\dfrac{(300\ \text{in})}{3(29\text{x}10^6\text{psi})310\ \text{in}^4}$

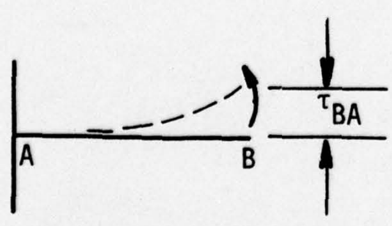
$= 1.0011$ in

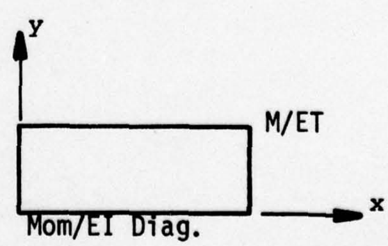
Difference in predicted deflections is 0.8 percent.

Load Case 3 (300,000 in-lb concentrated moment) y-translation

SAP IV Node 6 $\Delta_y = +1.5017$ in

Strength of Materials - Moment area





$$\tau BA = \frac{M}{EI} \times \ell \times \frac{\ell}{2} = \frac{M\ell^2}{2EI} = \Delta y = \frac{300{,}000\ \text{in-lb}(300\ \text{in})^2}{2(29\text{x}10^6\text{psi})310\ \text{in}^4} = 1.5017\ \text{in}$$

Load Case 4   (5000 in-lb torque) Angle of Twist

SAP IV x rot. = 0.14067 radians

Node 6

Strength of Materials $\rho = \frac{TL}{JG} = \frac{(5000 \text{ in-lb})(300 \text{ in})}{(0.956 \text{ in}^4)(11.154 \times 10^3 \text{ in}^4)}$

$= 0.14067$ radians

Load Case 5   (Combined loads)   y-translation

SAP IV $\Delta_y = +0.49289$ in

Node 6

Strength of Materials $\Delta_y = -1.0011+1.5017 = 0.5006$ in

Difference in predicted deflections is 1.56 percent.

2.2 Effect of Shear Deformations on a Deep Beam and a Standard Beam

2.2.1 Problem Description

As seen in problem 2.1, the inclusion of shear deformations in an analysis leads to computed deflections somewhat larger than deflections computed by standard means. In an attempt to study the effect shear deformations have on the deflections computed for a standard beam and a "deep" beam, analyses were made on a standard 15-foot cantilever and a deep 15-foot cantilever. For each beam, analyses were made including shear deformations and not including shear deformations. A "deep" beam was considered to be a beam with a length to depth ratio of 5:1 or less (see Figure 13).

The following problems were considered:

2707

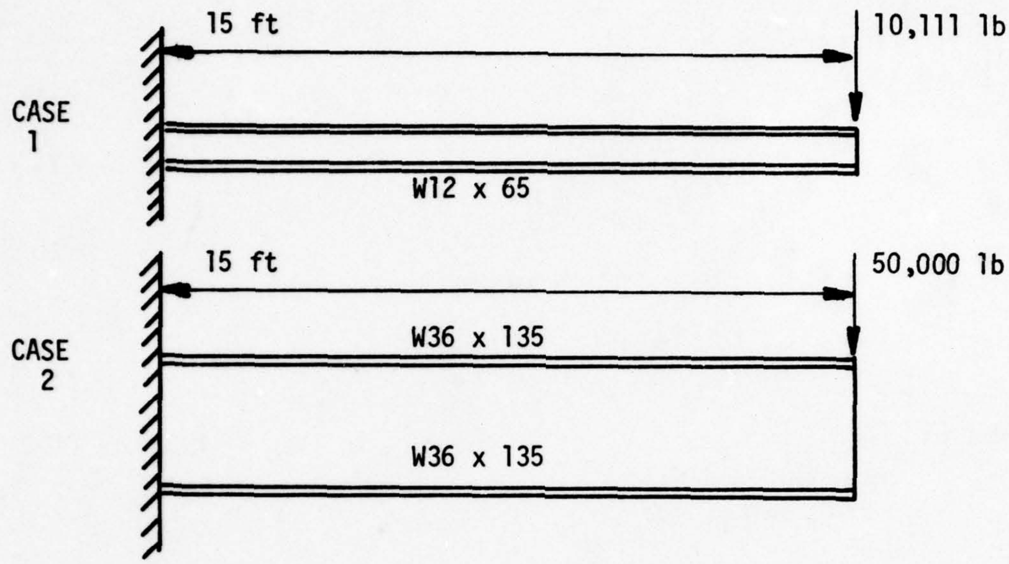


Figure 13. Shallow and Deep Cantilever Beams

In both cases loads were chosen that would yield a bending stress of approximately 20.5 ksi at the fixed end.

2.2.2 Three 3-D beam elements were used for both problems. The arrangements of the nodes and beam elements used in the analysis are shown in Figure 14.

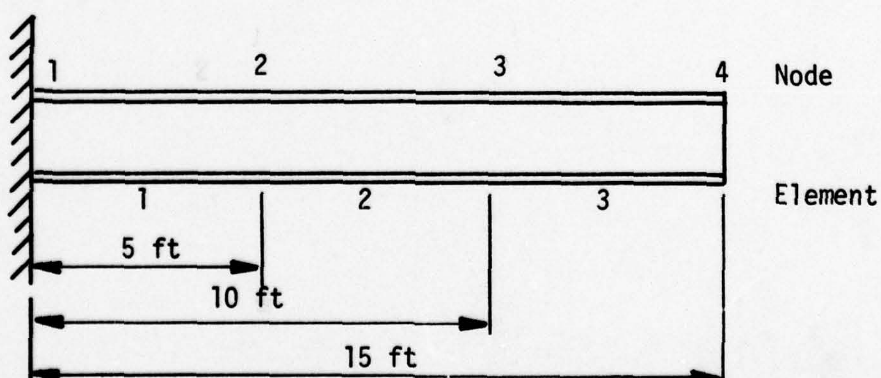


Figure 14. Cantilever Beam Element Assignment

2.2.3 Input Data - Case I with Shear

```
HEADER=*STD. BEAM SHEAR W12X65
NUMNP=5,NELTYP=1,LL=1,
IX(1,5)=1,1,1,1,1,1,
IX(2 4)=0,0,1,1,1,0,
XYZT(1)=0.,0.,0.,0.,
XYZT(2)=60.,0.,0.,
XYZT(4)=180.,
XYZT(5)=0.,5.,
NBEAM=3,BNEPC=1,BNMPC=1,
BMPC(1)=2.9E7,.3,15.22,490.,
BEPC(1)=19.1,4.73,4.73,2.19,175.,533.,
BEAM(1)=1,2,5,1,1
BEAM(3)=3,4,5,1,1
CLMD(4,1)=,-10111.,
'
```

2.2.4 Input Data - Case I without Shear

```
HEADER=*STD.    NO SHEAR W12X65
NUMNP=5,NELTYP=1,LL=1,
IX(1,5)=1.1,1,1,1,1,
IX(2 4)=0.0,1,1,1,0,
XYZT(1)=0.,0.,0.,0.,
XYZT(2)=60.,0.,0.,
XYZT(4)=180.,
XYZT(5)=0.,5.,
NBEAM=3,BNEPC=1,BNMPC=1,
BMPC(1)=2.9E7,.3,15.22,490.,
BEPC(1)=19.1,,,2.19,175.,533.,
BEAM(1)=1,2,5,1,1
BEAM(3)=3,4,5,1,1
CLMD(4,1)=,-10111.,
'
```

2.2.5 Input Data - Case II with Shear

```
HEADER=*DEEP BEAM SHEAR  W36X135
NUMNP=5,NELTYP=1,LL=1
IX(1,5)=1,1,1,1,1,1,
IX(2 4)=0,0,1,1,1,0,
XYZT(1)=0.,
XYZT(2)=60.,
XYZT(4)=180.,
XYZT(5)=0.,5.,
NBEAM=3,BNEPC=1,BNMPC=1,
BMPC(1)=2.9E7,.3,15.22,490.,
BEPC(1)=39.8,21.26,21.26,7.03,226.,7820.,
BEAM(1)=1,2,5,1,1
BEAM(3)=3,4,5,1,1
CLMD(4,1)=,-50000.,
'
```

2.2.6 Input Data - Case II without Shear

```
HEADER=*BEEP BEAM NO SHEAR   W36X135
NUMNP=5,NELTYP=1,LL=1
IX(1,5)=1,1,1,1,1,1,
IX(2 4)=0,0,1,1,1,0,
XYZT(1)=0.,
XYZT(2)=60.,
XYZT(4)=180.,
XYZT(5)=0.,5.,
NBEAM=3,BNEPC=1,BNMPC=1,
BMPC(1)=2.9E7,.3,15.22,490.,
BEPC(1)=39.8,,,7.03,226.,7820.
BEAM(1)=1,2,5,1,1
BEAM(3)=3,4,5,1,1
CLMD(4,1)=,-50000.,
'
```

2.2.7 Notes on Input Data

The input data for the two cases involving a standard beam (W 12 x 65) are very similar to the input data discussed when considering the analysis of a cantilever beam under five loading cases. One should note that for the analysis considering shear deformations, the element geometric properties include an area of 4.73 square inches that is associated with shear forces in the local two direction, whereas, for the second case the input does not include this piece of data and the analysis will not include shear deformations.

For the two cases involving a deep beam (W 36 x 135) it should be noted that for the first case, where shear deformations are taken into account, the element geometric properties include an area of 21.26 square inches associated with shear in the local two direction. In the second case, where shear deformations are not taken into account, this shear area has not been included.

2.2.8 Results

For the standard beam (W 12 x 65) the maximum deflection computed by SAP IV including shear deformations was Δ_y = 1.3061 inches. The maximum deflection computed by SAP IV not including shear deformations was Δ_y = 1.2716 inches which compares to within five places with the strength of materials solutions. The error in the strength of materials solution was 2.7 percent.

For the deep beam (W 36 x 135) the maximum deflection computed by SAP IV including shear deformations was Δ_y = 0.46656 inch. The maximum deflection computed by SAP IV, not considering shear deformations, was Δ_y = 0.42861 inch, which again compared to within five places with the strength of materials solution. The error in the strength of materials solution, this time, was 8.9 percent. Thus, for extremely deep, short beams, the error encountered when computing deflections without considering shear deformations begins to be significant. Therefore, in any analysis of an aircraft shelter where there is some question as to whether or not the shelter section may constitute a "deep" beam, shear deformation should be taken into account. As the input shows, this can be done with very little effort. All that is required is to include in the element geometry input the areas associated with shear forces in the local two direction. (Figure 15.)

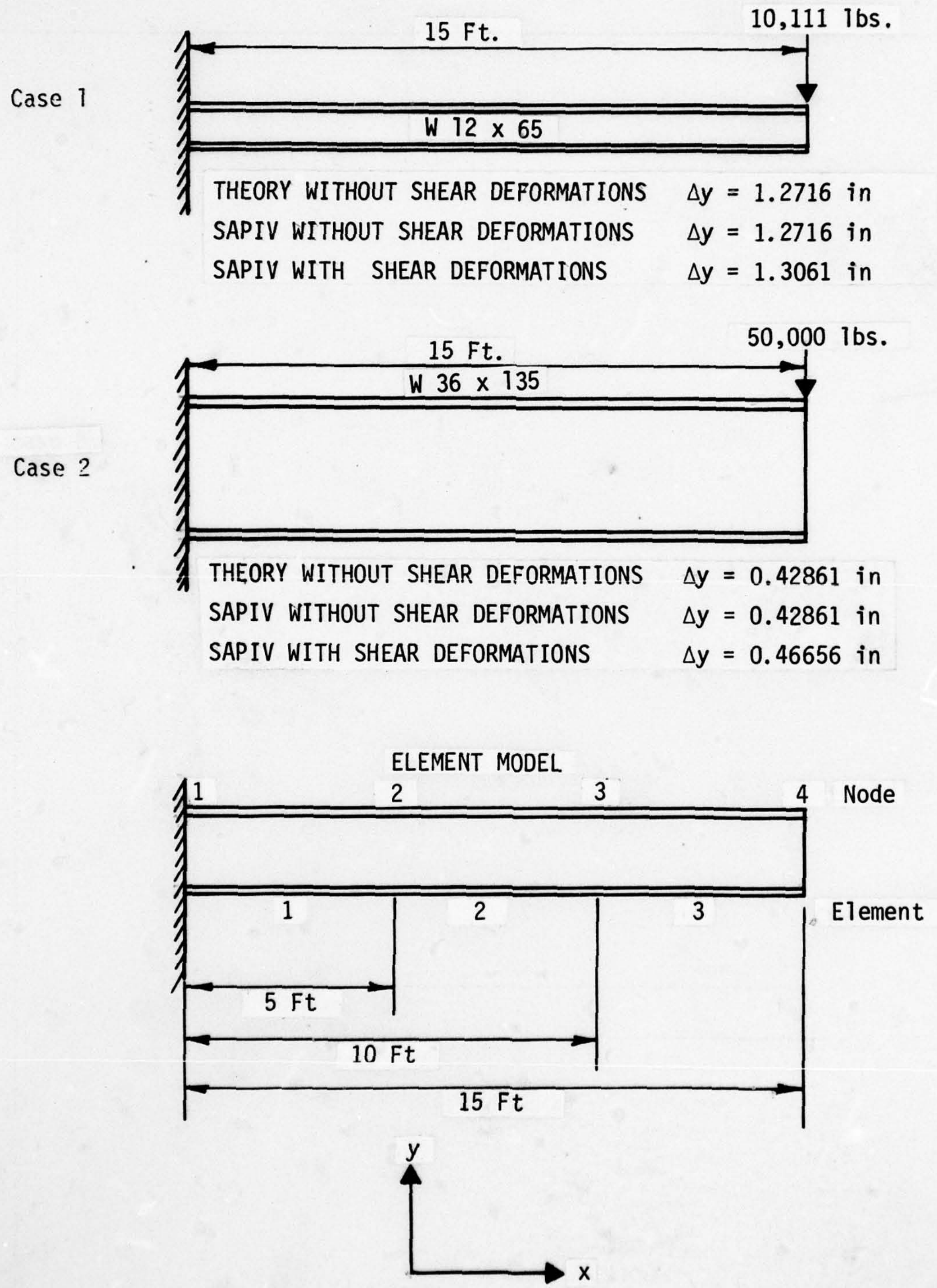


Figure 15. Effect of Shear Deformations

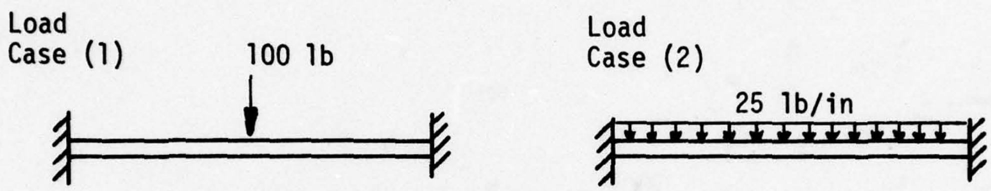
3. Fixed-Fixed Beam

3.1 Static Analysis of Fixed-Fixed Beam (Figure 16)

3.1.1 A box beam fixed at both ends is subjected to

1. A concentrated load at the center

2. A uniformly distributed load

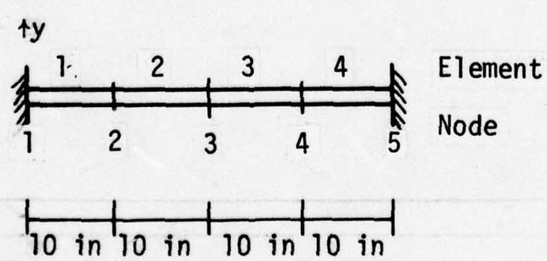


Material = Steel

Member: 4 in x 4 in x 40 in box beam with wall thickness 1/4 inch

Figure 16. Fixed-Fixed Beam Load Cases

3.1.2 A group of four 3-D beam elements is used for this analysis with the location of the nodes and the element numbers (square boxes) shown in Figure 17.



Material = Steel

Member: 4 in x 4 in x 40 in box beam with wall thickness 1/4 in

Figure 17. Element Assignment - Fixed-Fixed Beams

The input data for these problems are as follows:

3.1.3 Input Data - Case 1

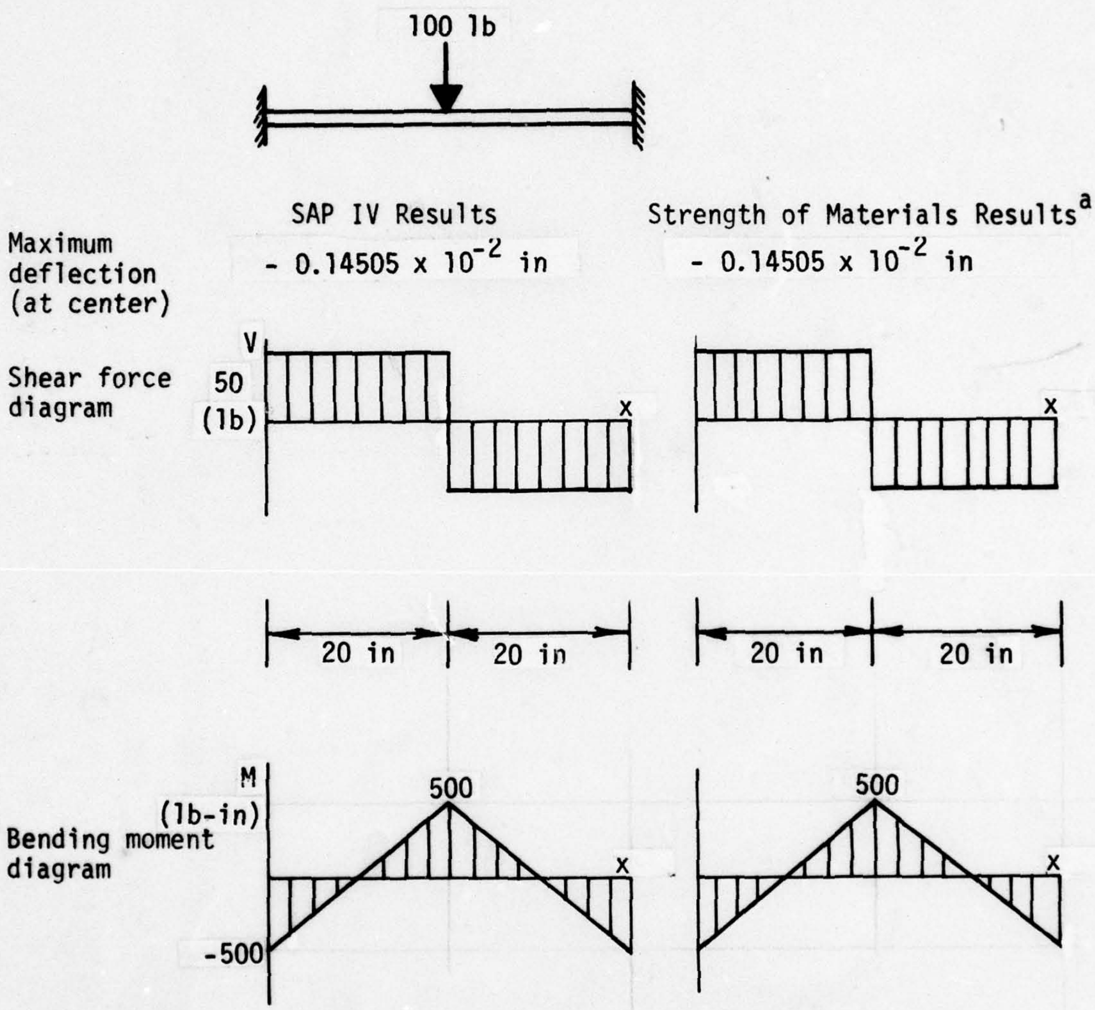
```
HEADER=*STATIC BEAM PROBLEM   *
NUMNP=6,NFLTYP=1,LL=1,
IX(1,5,6)=1,1,1,1,1,1,
IX(2 4)=0,0,1,1,1,0,
XYZT(1)=
XYZT(2)=10.,
XYZT(5)=40.,
XYZT(6)=0.,1.,
NBEAM=4,3NEPC=1,BNMPC=1,
BMPC(1)=3.0E7,.333,.0007346
BEPC(1)=1.59,,,.079,.766,.766
BEAM(1)=1,2,6,1,1
BEAM(4)=4,5,6,1,1
CLMD(3,1)=,-100.,
'
```

3.1.4 Input Data - Case 2

```
HEADER=* STATIC BEAM PROBLEM        *
NUMNP=6,NFLTYP=1,LL=1
IX(1,5,6)=1,1,1,1,1,1,
IX(2 4)=0,0,1,1,1,0
XYZT(1)=
XYZT(2)=10.,
XYZT(5)=40.,
XYZT(6)=0.,1.,
NBEAM=4,BNEPC=1,BNMPC=1
BMPC(1)=3.0E7,.333,.0007346,-15.72
BEPC(1)=1.59,,,.079,.766,.766
BEAM(1)=1,2,6,1,1,
BEAM(4)=4,5,6,1,1,
FLM(1)=1.
BELFY=1.,
'
```

3.1.5 Comparison of SAP IV Results with Strength of Materials Solution

Case 1. Concentrated Load at Center.



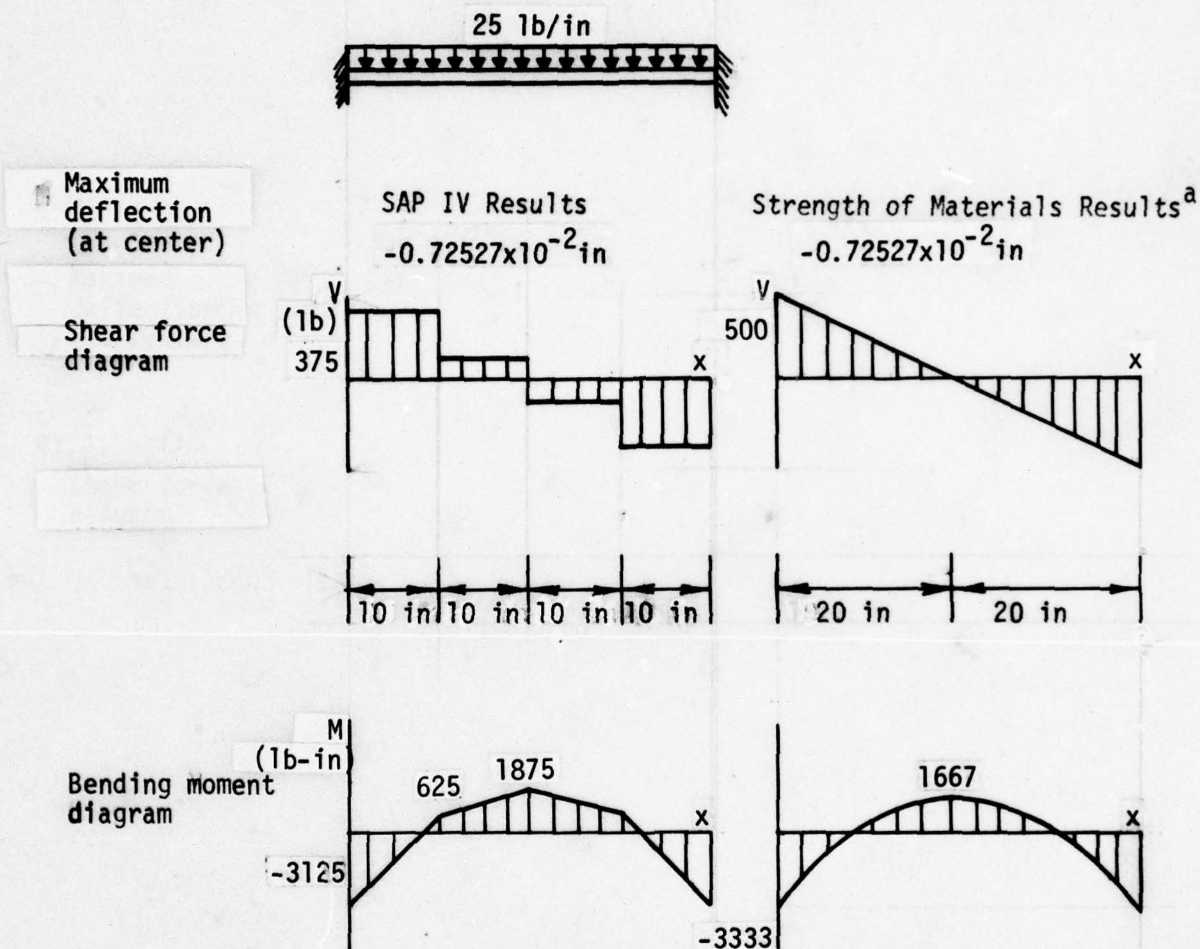
[a]"Manual of Steel Construction," Seventh Edition, AISC, pp 2-203.

Figure 18. Static Results - Fixed-Fixed Beam Point Load

The results of Figure 18 indicate the following:

1. The maximum deflections agree to within five significant figures.
2. The shear force diagrams are the same, as are the bending moment diagrams.

Case 2. Uniformly Distributed Load.



[a]"Manual of Steel Construction," Seventh Edition, AISC., pp 2-203.

Figure 18a. Static Results - Fixed-Fixed Beams - Distributed Load

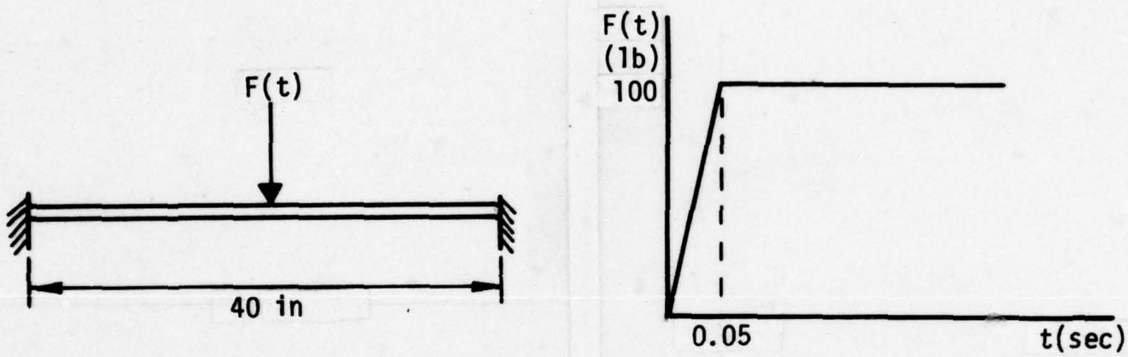
The results of Figure 18a show that:

1. The maximum defections agree to within five significant figures.

2. The difference between the two shearing force diagrams and the two bending moment diagrams is due to the assumptions of constant element strain in SAP IV.

3.2 Dynamic Analysis of Fixed-Fixed Beam

3.2.1 A box beam (Figure 19) fixed at both ends is subjected to a time dependent load at the center as follows:



Material = Steel

Member = 4 x 4 x 40 inches box beam
with wall thickness = 1/4 inch

Figure 19. Fixed-Fixed Beam - Dynamic Point Load

3.2.2 The finite element model and location of nodes are the same as for the static analysis (3.1.2).

Two different analysis methods, mode superposition and direct step-by-step integration, were used. The input data for these analyses are as follows:

3.2.3 Mode Superposition

```
HEADER=*DYNAMIC ANALYSIS OF A FIXED-FIXED BEAM
NUMNP=6,NELTYP=1,NF=6,NDYN=2,
IX(1,5,6)=1,1,1,1,1,1,
IX(2 4)=0,0,1,1,1,0,
XYZT(1)=
XYZT(2)=10.,
XYZT(5)=40.,
XYZT(6)=40.,1.,
NBEAM=4,BNEPC=1,BNMPC=1
BMPC(1)=3.0E7,.333,.0007346
BEPC(1)=1.59,,,.079,.766,.766
BEAM(1)=1,2,6,1,1
BEAM(4)=4,5,6,1,1
IFPR=1,NFN=1,NT=4000,NOT=100,DT=.0001
NP(3,2)=1,,1.
NLP(1)=3,-100.
T(1,1)=0.,T(1,2)=.05,T(1,3)=5.0
F(1,1)=0.,F(1,2)=1.,F(1,3)=1.
KKK=2
ICOMP(2,3)=1,2,6
KKKS=2
IS(2,2)=1,2,6,7,8,12
IS(2,3)=1,2,6
,
```

3.2.4 Direct Integration

```
HEADER=*DYNAMIC ANALYSIS OF A FIXED-FIXED BEAM
NUMNP=6,NELTYP=1,NF=6,NDYN=4
IX(1,5,6)=1,1,1,1,1,1,
IX(2 4)=0,0,1,1,1,0,
XYZT(1)=
XYZT(2)=10.,
XYZT(5)=40.,
XYZT(6)=40.,1.,
NBEAM=4,BNEPC=1,BNMPC=1,
BMPC(1)=3.07,.333,.0007346,
BEPC(1)=1.59,,,.079,.766,.766
BEAM(1)=1,2,6,1,1
BEAM(4)=4,5,6,1,1
NFN=1,NT=4000,NOT=100,DT=.0001
NP(3,2)=1,,1.
NLP(1)=3,-100.
T(1,1)=0.,T(1,2)=.05,T(1,3)=5.
F(1,1)=0.,F(1,2)=1.,F(1,3)=1.
KKK=2,
ICOMP(2)=1,2,6
ICOMP(3)=1,2,6
KKKS=2,
IS(2,2)=1,2,6,7,8,12
IS(2,3)=1,2,6
,
```

3.2.5 Results

Both the vertical and horizontal displacements of the beam center (node 3) are presented in Figure 20. The horizontal component is zero for all time while the vertical component increases negatively to an average value corresponding to the static deflection.

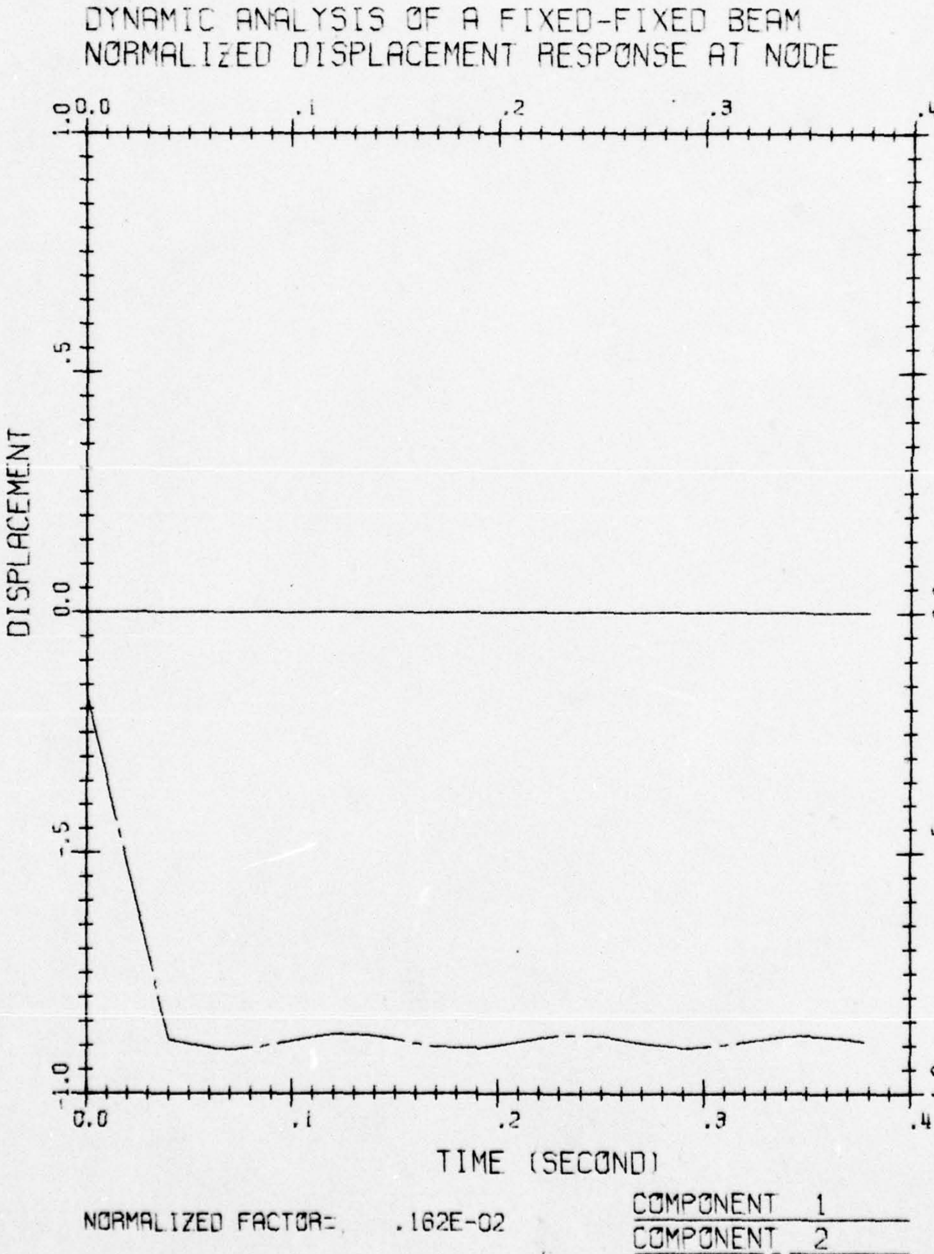


Figure 20. Midpoint Displacement Response (Fixed-Fixed Beam)

4. PLANE FRAMES

4.1 Static Analysis of Rectangular Frame Under Four Different Loads.

4.1.1 Problem Description

A 10-foot by 10-foot rectangular frame was subjected to four different loading conditions. These four load cases are illustrated in Figure 21.

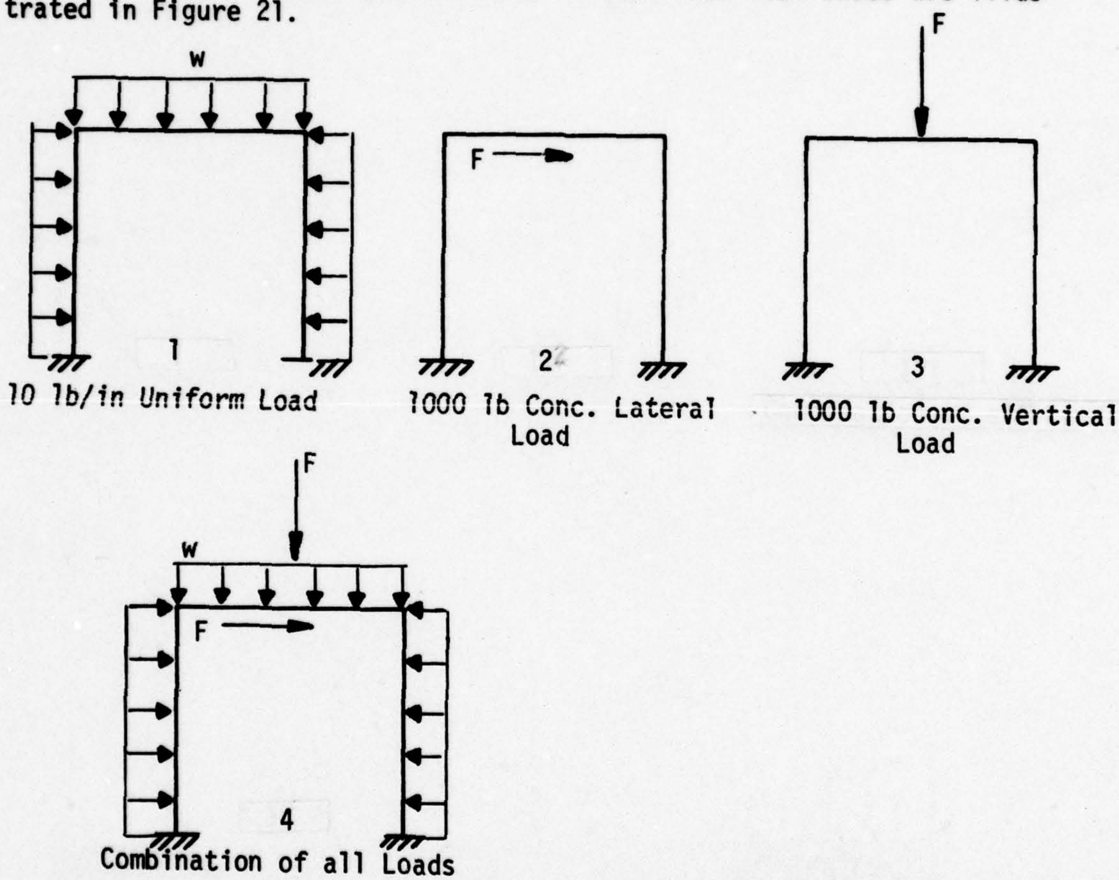


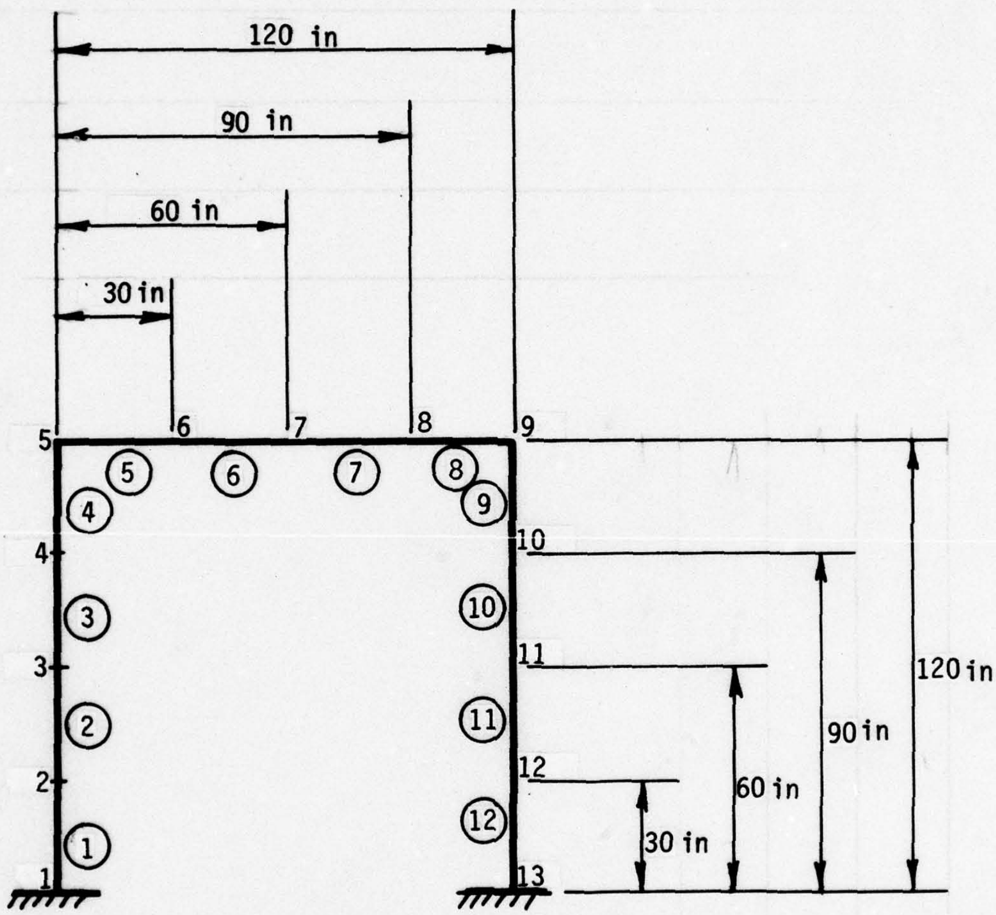
Figure 21. Rectangular Frame-Static Load Cases

The frame was composed of W 8 x 15 horizontal and vertical structural steel members with the following properties:

$A = 4.43^{2}\text{in}$; $I_{xx} = 48.1\ \text{in}^4$; $I_{yy} = 3.40\ \text{in}^4$; $J = 0.136\ \text{in}^4$

$E = 20 \times 10^6\ \text{lbs/in}^2$; $v = 0.3$

4.1.2 Twelve 3-D beam elements were used in the analysis. The assignment of nodes and beam elements is shown in Figure 22.



A 10 foot by 10 foot rectangular frame composed of 8 WF 15 horizontal and vertical structural steel members

Figure 22. Element Assignment - Rectangular Frame

4.1.3 Input Data - Rectangular - Frame - Static

```
HEADER=*STATIC ANAL. RECT. FRAME UNIF. AND CONC. LOADS
NUMNP=13,NELTYP=1,LL=4
IX(1,13)=1,1,1,1,1,1,
XYZT(1)=
XYZT(2)=0.,30.,
XYZT(5)=0.,120.
XYZT(6)=30.,120.,
XYZT(9)=120.,120.,
XYZT(10)=120.,90.,
XYZT(13)=120.,0.,
IX(2 12)=0,0,1,1,1,0,
NBEAM=12,BNEPC=1,BNMPC=1,
BMPC(1)=2.9E7,.3,7.34E-4,.284
BEPC(1)=4.43,,,.136,3.4,48.1,
BEAM(1)=1,2,6,1,1
BEAM(4)=4,5,6,1,1
BEAM(5)=5,6,4,1,1
BEAM(8)=8,9,4,1,1
BEAM(9)=9,10,8,1,1
BEAM(12)=12,13,4,1,1
CLMD(1,1)=150.
CLMD(1,4)=150.
CLMD(2,1)=300.
CLMD(2,4)=300.
CLMD(3,1)=300.
CLMD(3,4)=300.
CLMD(4,1)=300.
CLMD(4,4)=300.
CLMD(5,1)=150.,-150.,
CLMD(5,4)=150.,-150.,
CLMD(6,1)=,-300.,
CLMD(6,4)=,-300.,
CLMD(7,1)=,-300.,
CLMD(7,2)=1000.,
CLMD(7,3)=,-1000.,
CLMD(7,4)=1000.,-1300.,
CLMD(8,1)=,-300.,
CLMD(8,4)=,-300.,
CLMD(9,1)=-150.,-150.,
CLMD(9,4)=-150.,-150.,
CLMD(10,1)=-300.,
CLMD(10,4)=-300.,
CLMD(11,1)=-300.,
CLMD(11,4)=-300.,
CLMD(12,1)=-300.,
CLMD(12,4)=-300.,
CLMD(13,1)=-150.,
CLMD(13,4)=-150.,
'
```

4.1.4 Results. A comparison of moments in in/lb as computed by SAP IV and a standard moment distribution technique for the first three load cases is shown in Figure 23.

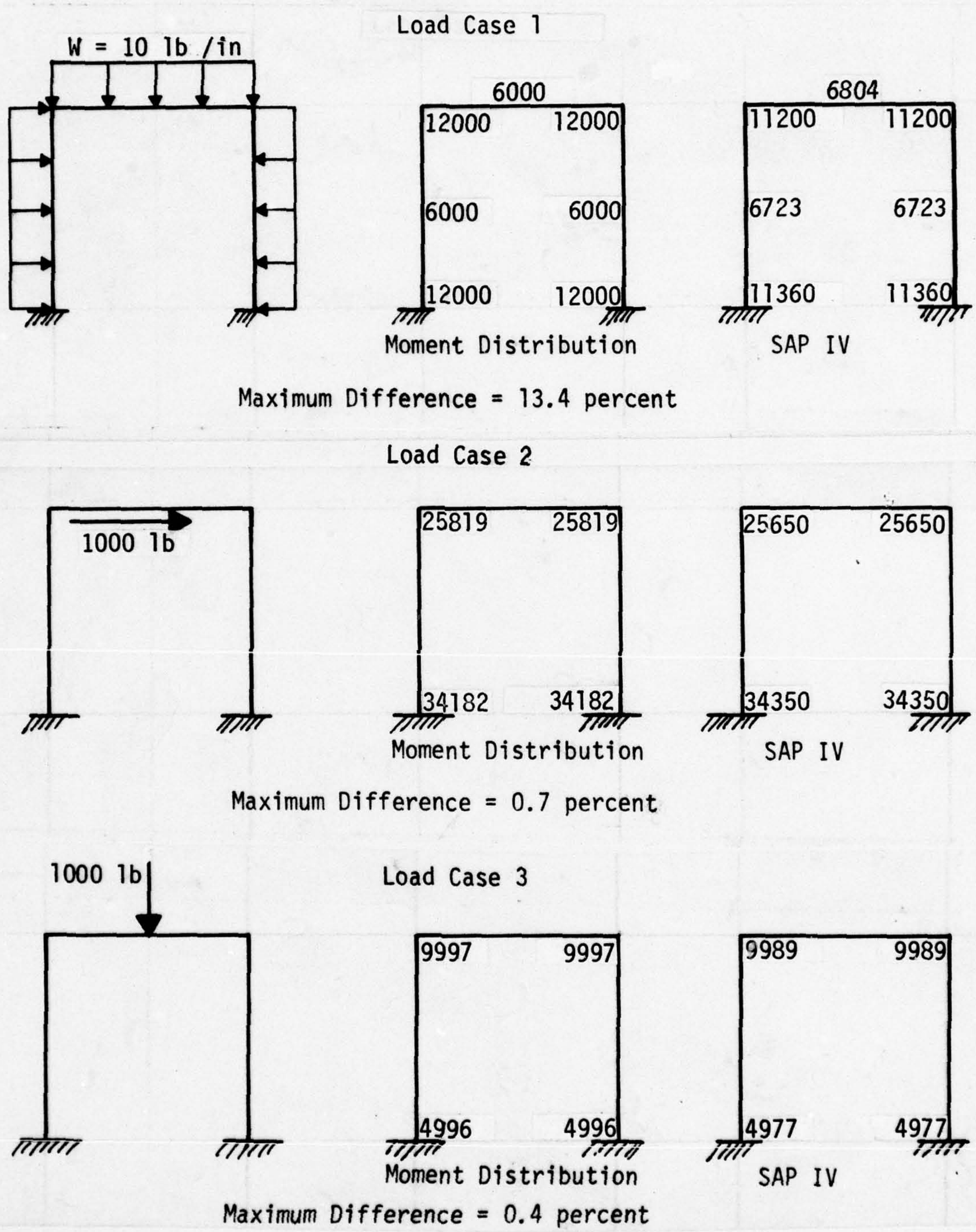


Figure 23. Static Results - Rectangular Frame

It should be noted that the maximum difference in computed moments occurred for load case 1. This is probably because the uniform load was approximated by equivalent concentrated loads applied at the various nodes. A more accurate analysis could be achieved by including more beam elements in the numerical analysis.

4.2 Response Time History of a Rectangular Frame (Figure 24) Subjected to a Traveling Pressure Wave

4.2.1 Problem Description

The same 10-by 10-foot rectangular frame considered in problem 4.1 was struck by a pressure wave of 10 lb/in traveling at 200 ft/sec.

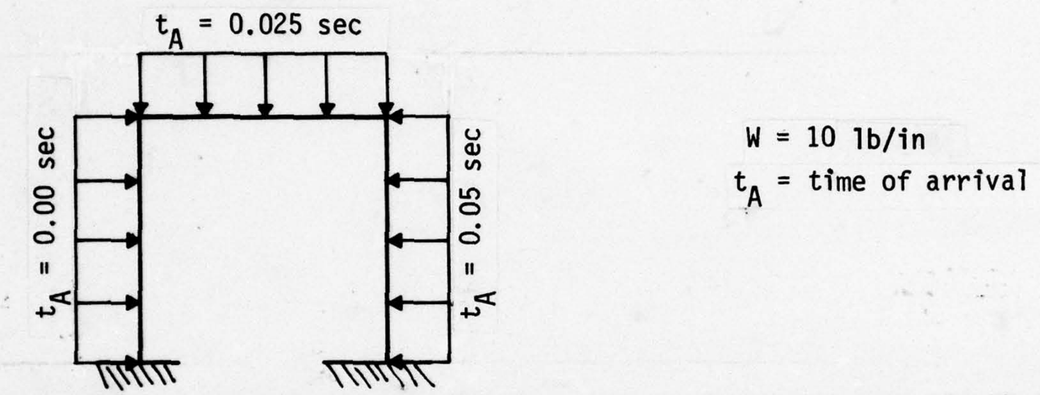


Figure 24. Dynamic Loading - Rectangular Frame

4.2.2 Finite Element Model

The same 12 3-D beam elements as were used in problem 4.1 were used in this problem. The assignment of nodes and beam elements is shown in Figure 25.

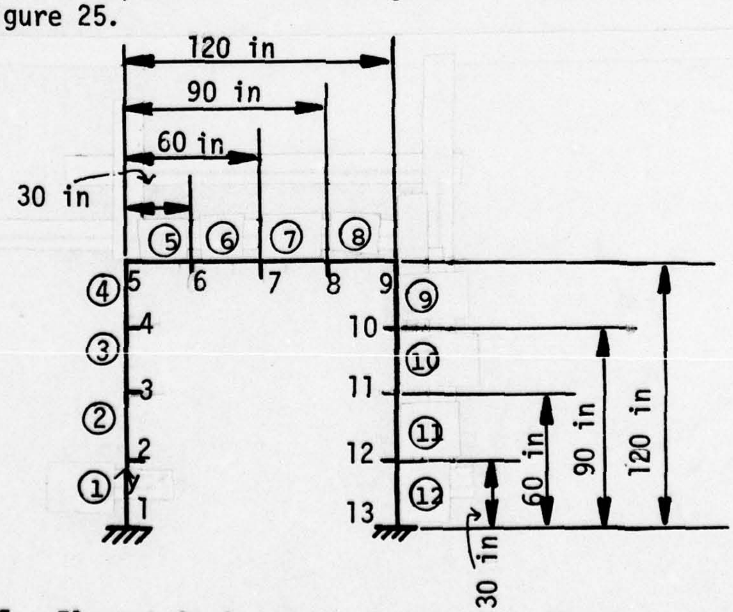


Figure 25. Element Assignment - Rectangular Frame

4.2.3 Input Data - Rectangular Frame - Travelling Pressure Wave

```
HEADER=*RECT. FRAME TRAVELING PRESS. WAVE
NUMNP=13,NELTYP=1,NF=10,NDYN=2,
IX(1,13)=1,1,1,1,1,1,
IX(2 12)=0,0,1,1,1,0,
XYZT(1)=
XYZT(2)=0.,30.,
XYZT(5)=0.,120.,
XYZT(6)=30.,120.,
XYZT(9)=120.,120.,
XYZT(10)=120.,90.,
XYZT(12)=120.,30.,
XYZT(13)=120.,0.,
NBEAM=12,BNEPC=1,BNMPC=1,
BMPC(1)=2.9E7,.3,7.34E-4,.284
BEPC(1)=4.43,,,.136,3.4,48.1,
BEAM(1)=1,2,6,1,1
BEAM(4)=4,5,6,1,1
BEAM(5)=5,6,4,1,1
BEAM(8)=8,9,4,1,1
BEAM(9)=9,10,8,1,1
BEAM(12)=12,13,8,1,1
IFPR=1,NFN=1,NAT=3,NT=5000,DT=.0002,NOT=10
NP(1,1)=1,1,150.
NP(2,1)=1,1,300.
NP(3,1)=1,1,300.
NP(4,1)=1,1,300.
NP(5,1)=1,1,150.
NP(5,2)=1,1,-150.
NP(6,2)=1,2,-300.
NP(7,2)=1,2,-300.
NP(8,2)=1,2,-300.
NP(9,1)=1,3,-150.
NP(9,2)=1,3,-150.
NP(10,1)=1,3,-300.
NP(11,1)=1,3,-300.
NP(12,1)=1,3,-300.
NP(13,1)=1,3,-150.
AT(1)=0.,AT(2)=.025,AT(3)=.05,
NLP(1)=2,1.
T(1,1)=0..T(1,2)=2.
F(1,1)=1..F(1,2)=1.
KKK=2,ICOMP(1,3,5 9,11,13)=1,2,3,6
KKKS=2,
IS(2,1)=1,2,3,6,7,8,9,12
IS(2,2)=1,2,3,6,7,8,9,12
IS(2,4)=1,2,3,6,7,8,9,12
IS(2,5)= 1,2,3,6,7,8,9,12
IS(2,6)= 1,2,3,6,7,8,9,12
IS(2,7)= 1,2,3,6,7,8,9,12
IS(2,8)= 1,2,3,6,7,8,9,12
IS(2,9)= 1,2,3,6,7,8,9,12
IS(2,11)=1,2,3,6,7,8,9,12
IS(2,12)=1,2,3,6,7,8,9,12
```

4.2.4 Results

The first part of the results gives the eigenvalues and mode shapes of the frame. Figure 26 shows the first five eigenvalues and the mode shapes associated with the first three eigenvalues.

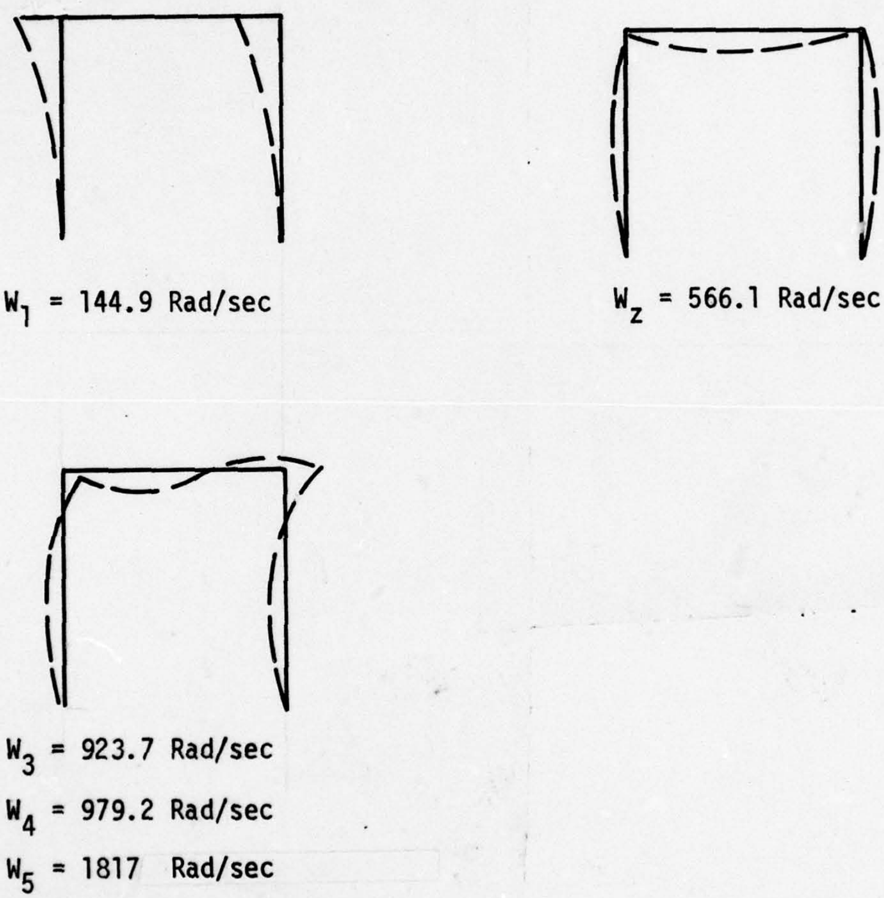


Figure 26. Rectangular Frame - Natural Frequencies and Mode Shapes

The displacement time history for node 7 is given in Figure 27. Components 1 and 2 in this figure correspond to the x and y displacements, respectively. To obtain absolute results the normalized values given in each figure must be multiplied by the normalized values given in each curve. For the stress time history shown in Figure 28, component 1 is the axial force at node 7, component 2 is the shear force at node 7 and component 3 is the out of plane shear force at node 7, zero for all time. All of these components act on element 7.

The displacement response of node 7 exhibits a period of 0.043 second, which corresponds to the first mode vibration period.

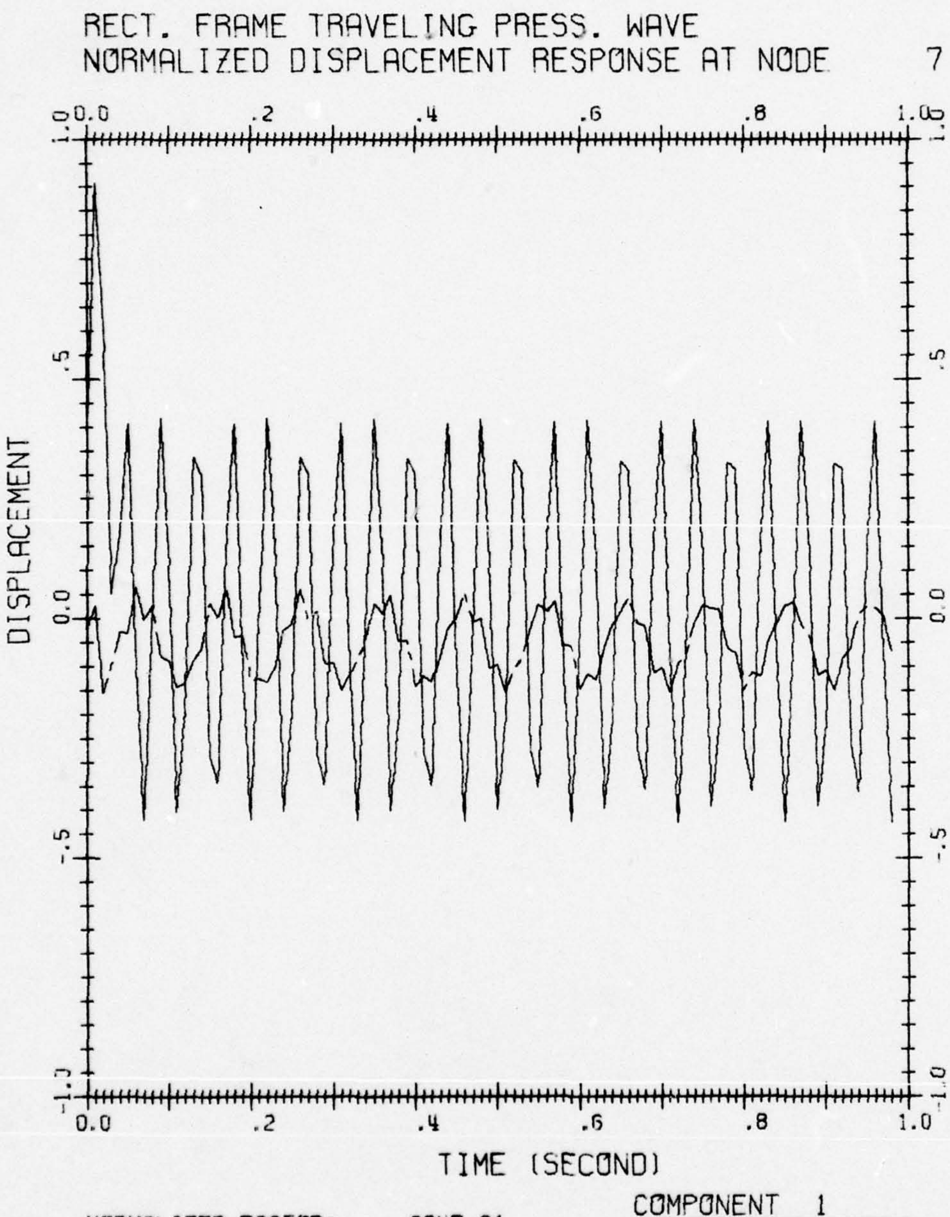


Figure 27. Nodal Displacement

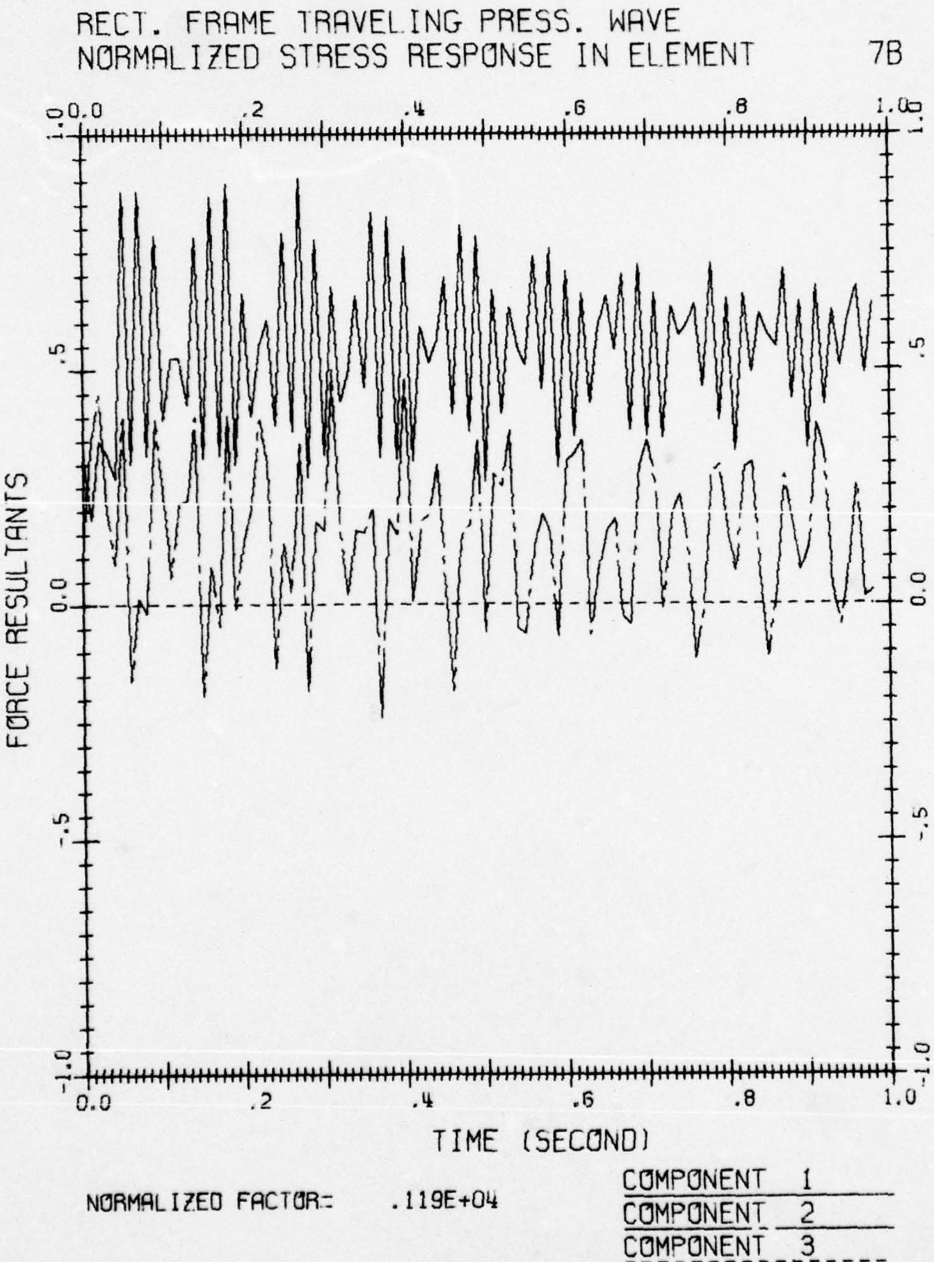


Figure 28. Element Forces

4.3 Static Analysis of a Polygonal Frame Under a Uniform Pressure

4.3.1 Problem Description

A five-member polygonal frame was subjected to a uniform load (Figure 29) of 10 lb/in. The corners of the frame were on a 24-foot arc to simulate the geometry of a typical aircraft shelter. The members of the frame were W 12 x 36 with properties:

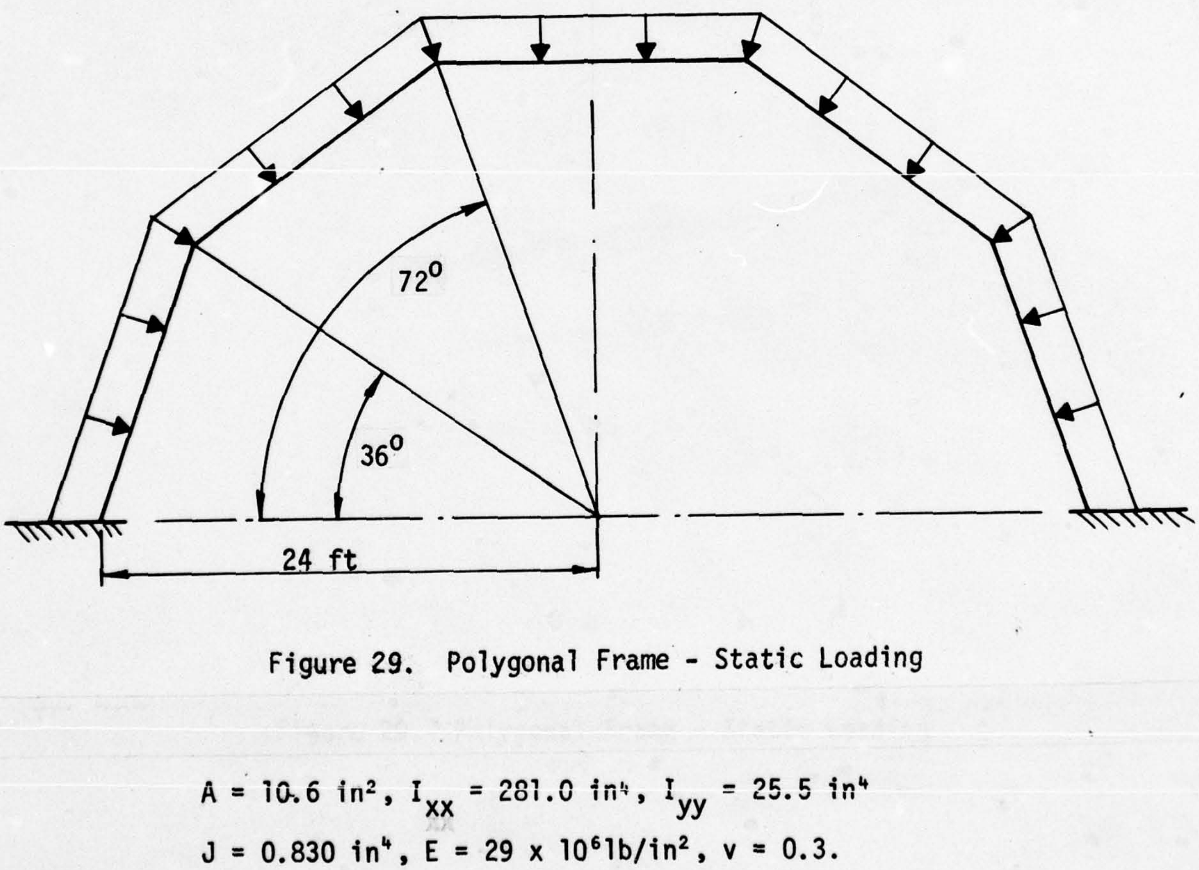


Figure 29. Polygonal Frame - Static Loading

$A = 10.6 \text{ in}^2$, $I_{xx} = 281.0 \text{ in}^4$, $I_{yy} = 25.5 \text{ in}^4$

$J = 0.830 \text{ in}^4$, $E = 29 \times 10^6 \text{lb/in}^2$, $v = 0.3$.

4.3.2 Analysis by Equivalent Fixed End Force

4.3.2.1 Problem Description

The polygonal frame described in the introduction will be analyzed by SAP IV with the uniform load represented by an equivalent fixed end force set.

4.3.2.2 Finite Element Model

The uniform load was replaced by equivalent fixed end forces for the computer analysis. Figure 30 shows the fixed end forces that were placed on each element, and the length of each element.

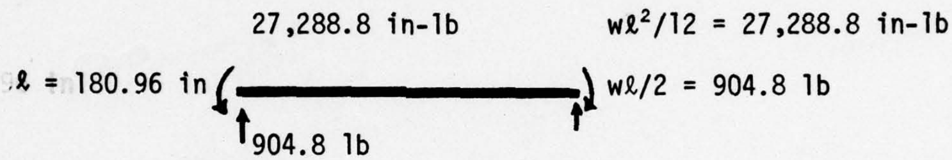


Figure 30. Fixed End Forces

Five 3-D beam elements were used in the analysis. The assignment of nodes and beam elements is shown in Figure 31.

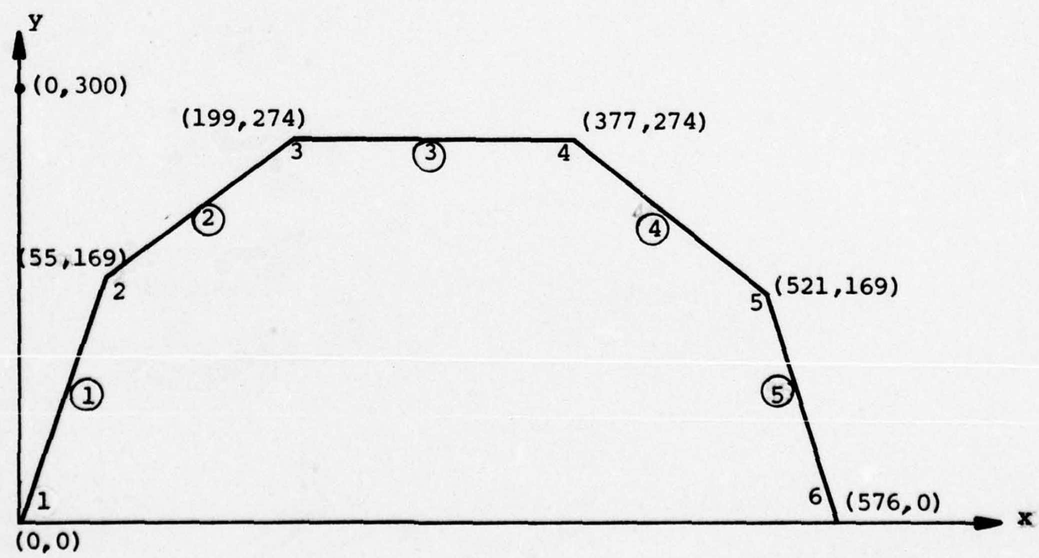


Figure 31. Element Assignment - Polygonal Frame (Five Elements)

The local coordinate system of a beam element is shown in Figure 32.

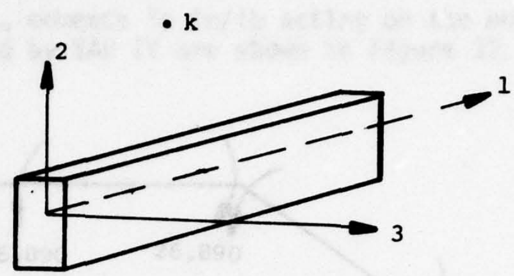


Figure 32. Local Coordinate System of Beam Element

The node k is any nodal point which lies in the local 1-2 plane but not on the 1 axis and is used to orient the element. For this problem node 7 was used as the node K for all of the beam elements. It should be noted that for elements 4 and 5 the node K lies below the 1 axis and the signs of the output forces with regard to the local coordinate system are reversed.

4.3.2.3 Input Data - Polygonal Frame - Static - Fixed End Forces

```
HEADER=*POLYGONAL FRAME STATIC UNIF. PRESS. FIXED END FORCES
NUMNP=7,NELTYP=1,LL=1,
IX(1,6,7)=1,1,1,1,1,1,
IX(2 5)=0,0,1,1,1,0,
XYZT(1)=
XYZT(2)=55.,169.,
XYZT(3)=199.,274.,
XYZT(4)=377.,274.,
XYZT(5)=521.,169.,
XYZT(6)=576.,0.
XYZT(7)=0.,300.,
NBEAM=5,BNEPC=1,BNFEFS=2,BNMPC=1,
BMPC(1)=2.9E7,.3,7.339E-4,.289
BEPC(1)=10.6,,,.83,25.5,281.,
BFEFI(1)=,904.8,,,,27288.8
BFEFJ(1)=,904.8,,,,-27288.8
BFEFI(2)=,-904.8,,,,-27288.8
BFEFJ(2)=,-904.8,,,,27288.8
BEAM(1)=1,2,7,1,1,1
BEAM(2)=2,3,7,1,1,1
BEAM(3)=3,4,7,1,1,1
BEAM(4)=4,5,7,1,1,2
BEAM(5)=5,6,7,1,1,2
ELM(1)=1.,
'
```

4.3.2.4 Results

The moments in in/lb acting on the ends of the various elements as computed by SAP IV are shown in Figure 33.

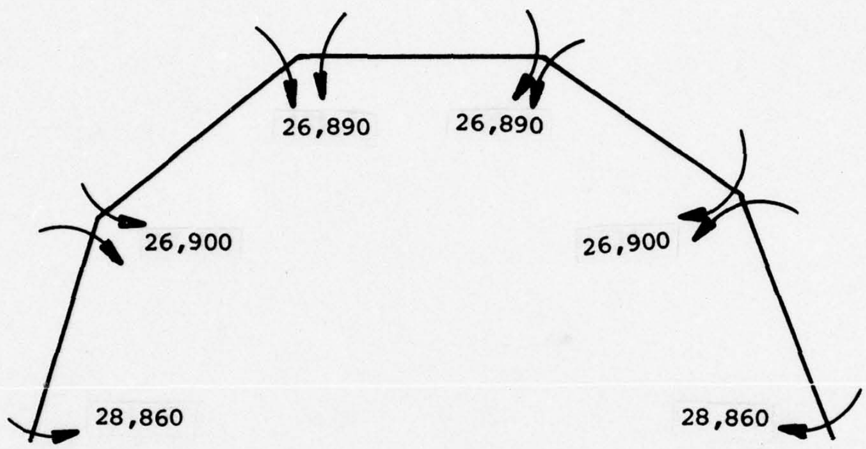


Figure 33. Bending Moments for Polygonal Frame (Equivalent Fixed End Forces)

It should be noted that these values are all within 5 percent of what would be computed by a moment distribution approach.

4.3.3 Analysis by Equivalent Concentrated Forces at Six Nodes

4.3.3.1 Problem Description

The five member polygonal frame (Figure 34) described in the introduction was subjected to the uniform load of 10 lb/in. For this analysis the uniform load was replaced by equivalent concentrated forces at the six nodes.

4.3.3.2 Finite Element Model

The uniform load was represented by the equivalent concentrated forces acting on the six nodes. The assignment of nodes and elements for this problem is the same as that described in problem 4.3.2.

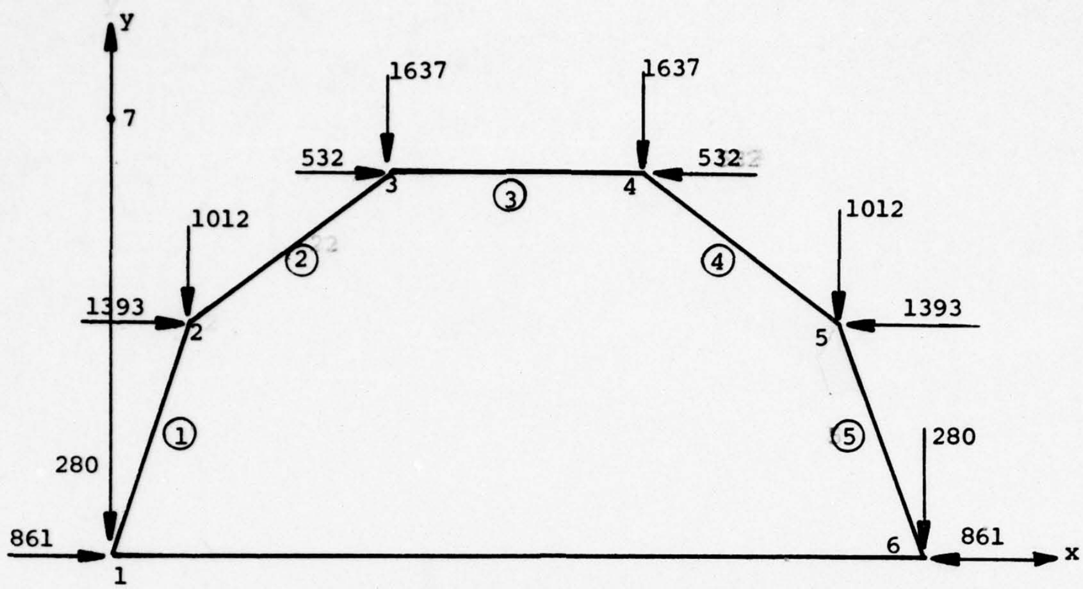


Figure 34. Element Assignment - Polygonal Frame

The concentrated loads refer to global coordinates x and y, therefore the sign reversal that was mentioned in problem 4.3.2 does not apply.

4.3.3.3 Input Data - Polygonal Frame - Static - Concentrated Forces at Six Nodes.

```
HEADER=*POLYGONAL FRAME STATIC UNIF. PRESS. FORCE 6 NODES
NUMNP=7,NELTYP=1,LL=1,
IX(1.6,7)=1,1.1,1,1,1,
IX(2 5)=0,0,1,1,1,C,
XYZT(1)=
XYZT(2)=55.,169.,
XYZT(3)=199.,274.,
XYZT(4)=377.,274.,
XYZT(5)=521.,169.,
XYZT(6)=576.,0.
XYZT(7)=0.,300.,
NBEAM=5,BNEPC=1,BNMPC=1,
BMPC(1)=2.9E7,.3,7.339E-4,.289
BEPC(1)=10.6,,,.83,25.5,281.,
BEAM(1)=1.2,7,1,1,1
BEAM(2)=2,3,7,1,1,1
BEAM(3)=3.4,7,1,1,1
BEAM(4)=4.5,7,1,1,1
BEAM(5)=5.6,7,1,1,1
CLMD(1,1)=861.,-280.,
CLMD(2,1)=1393.,-1012.,
CLMD(3,1)=532.,-1637.,
CLMD(4,1)=-532.,-1637.,
CLMD(5,1)=-1393.,-1012.,
CLMD(6,1)=-861.,-280.,
,
```

4.3.3.4 Results

The moments in in-lb acting of the ends of the five beam elements as computed by SAP IV are shown in Figure 35.

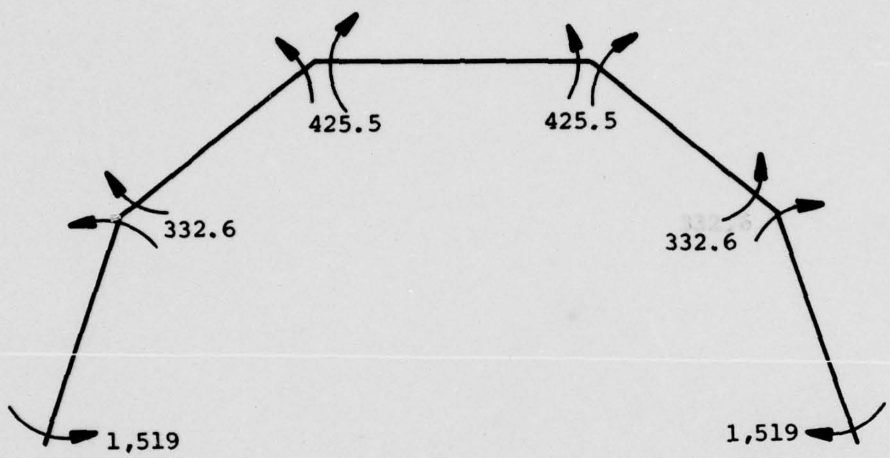


Figure 35. Bending Moments for Polygonal Frame (Equivalent Concentrated Forces)

When compared with the results obtained in problem 4.3.2, these moments are grossly different from those obtained by either a moment distribution approach or an equivalent fixed end force finite element analysis.

The reason that this equivalent nodal force approach was attempted is that in a dynamic analysis loads must be expressed in terms of equivalent nodal forces. As expressed in problem 4.3.4, a much more accurate analysis is achieved when the finite element model includes more nodal points.

4.3.4 Analysis by Equivalent Concentrated Forces at Sixteen Nodes.

4.3.4.1 Problem Description

For this analysis the uniform load of 10 lb/in, acting on the polygonal frame described in the introduction, was replaced by equivalent concentrated loads acting at 16 nodes.

4.3.4.2 Finite Element Model

Fifteen 3-D beam elements were used in the analysis. The assignment of nodes and beam elements is shown in Figure 36, along with global coordinates of the various nodes.

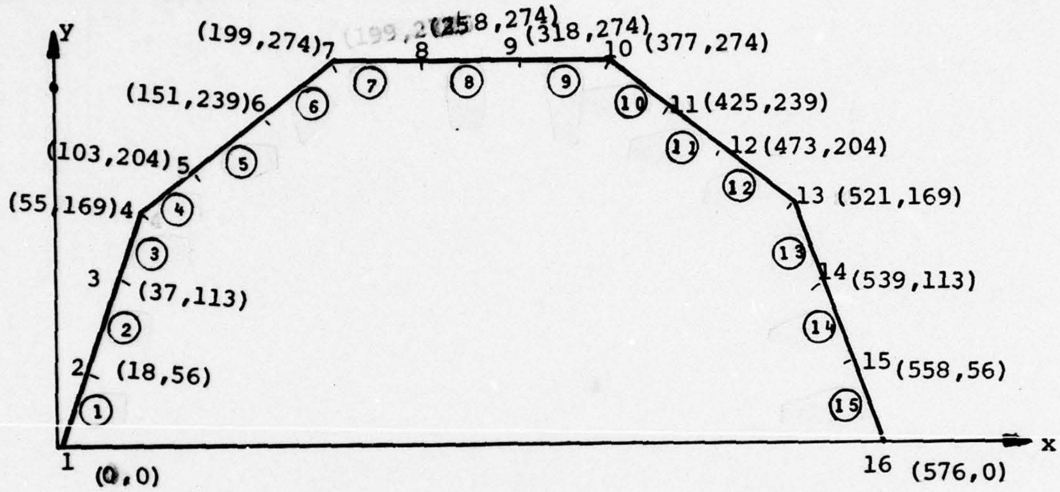


Figure 36. Element Assignment - 15 Elements

As stated, the uniform load was replaced by concentrated loads at 16 nodes. Figure 37 shows the x and y components of the loads that were used in the finite element model.

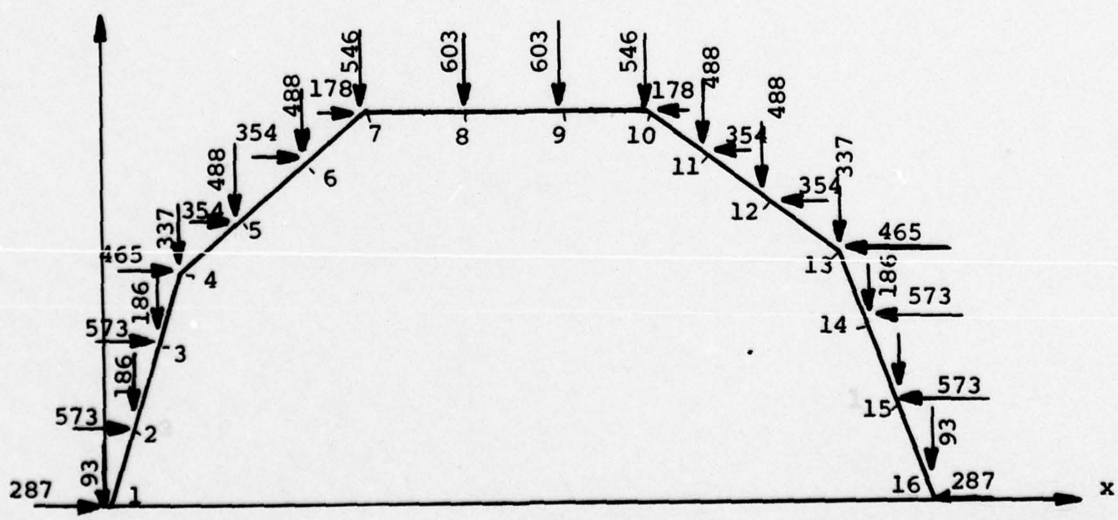


Figure 37. Polygonal Frame - Equivalent Concentrated Forces (16 Nodes)

4.3.4.3 Input Data - Polygonal Frame - Static - Concentrated Forces at 16 Nodes.

```
HEADER=*POLYGONAL FRAME STATIC UNIF. LOAD CONC. LOADS AT 16 NODES
NUMNP=17,NELTYP=1,LL=1,
IX(1,16,17)=1,1,1,1,1,1
IX(2 15)=0,0,1,1,1,0,
XYZT(1)=
XYZT(2)=18.,56.,
XYZT(3)=37.,113.,
XYZT(4)=55.,169.,
XYZT(5)=103.,204.,
XYZT(6)=151.,239.,
XYZT(7)=199.,274.,
XYZT(8)=258.,274.,
XYZT(9)=318.,274.,
XYZT(10)=377.,274.,
XYZT(11)=425.,239.,
XYZT(12)=473.,204.,
XYZT(13)=521.,169.,
XYZT(14)=539.,113.,
XYZT(15)=558.,56.,
XYZT(16)=576.,
XYZT(17)=,300.,
NBEAM=15,BNEPC=1,BNMPC=1,
BMPC(1)=2.9E7,.3,7.339E-4,.289
BEPC(1)=10.6,,,.83,25.5,281.,
BEAM(1)=1,2,17,1,1
BEAM(2)=2,3,17,1,1
BEAM(3)=3,4,17,1,1
BEAM(4)=4,5,17,1,1
BEAM(5)=5,6,17,1,1
BEAM(6)=6,7,17,1,1
BEAM(7)=7,8,17,1,1
BEAM(8)=8,9,17,1,1
BEAM(9)=9,10,17,1,1
BEAM(10)=10,11,17,1,1
BEAM(11)=11,12,17,1,1
BEAM(12)=12,13,17,1,1
BEAM(13)=13,14,17,1,1
BEAM(14)=14,15,17,1,1
BEAM(15)=15,16,17,1,1
CLMD(1,1)=287.,-93.,
CLMD(2,1)=573.,-186.,
CLMD(3,1)=573.,-186.,
CLMD(4,1)=465.,-337.,
CLMD(5,1)=354.,-488.,
CLMD(6,1)=354.,-488.,
CLMD(7,1)=178.,-546.,
CLMD(8,1)=,-603.,
CLMD(9,1)=,-603.,
CLMD(10,1)=-178.,-546.,
CLMD(11,1)=-354.,-488.,
CLMD(12,1)=-354.,-488.,
CLMD(13,1)=-465.,-337.,
CLMD(14,1)=-573.,-186.
CLMD(15,1)=-573.,-186.,
CLMD(16,1)=-287.,-186.,
```

4.3.4.4 Results

The moments in in-lb acting on the ends of elements 1, 3, 4, 6, 7, 9, 10, 12, 13 and 15 as computed by SAP IV are shown in Figure 38.

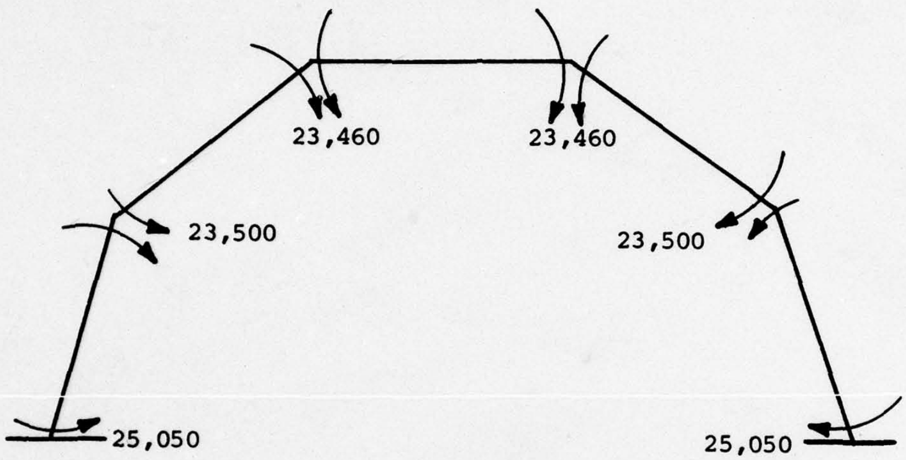


Figure 38. Bending Moments - Polygonal Frame (15 Elements)

The maximum variation from moments that would be computed by a moment distribution approach for the uniform load is 16.3 percent. A more accurate analysis would be achieved if the uniform load were distributed to more nodes. However, a simpler and more accurate static analysis is achieved by replacing the uniform load with equivalent fixed end forces as exemplified in problem 4.3.2. This technique of expressing a uniform load in terms of equivalent fixed end forces is recommended in the SAP IV manual as a method by which uniform loads may be specified for a static analysis. However, for a dynamic analysis (problem 4.3.3), a uniform load must be expressed in terms of nodal forces and this 16-node model will be used in the subsequent dynamic analysis.

4.4 Response Time History of a Polygonal Frame Subjected to a Traveling Uniform Load.

4.4.1 Problem Description

The five-sided polygonal frame discussed in problem 4.3 was subject to a pressure wave of magnitude 10 lb/in traveling at 1000

ft/sec. As in problem 4.3.4, the uniform load was replaced by equivalent concentrated force acting at 16 nodes (Figure 39).

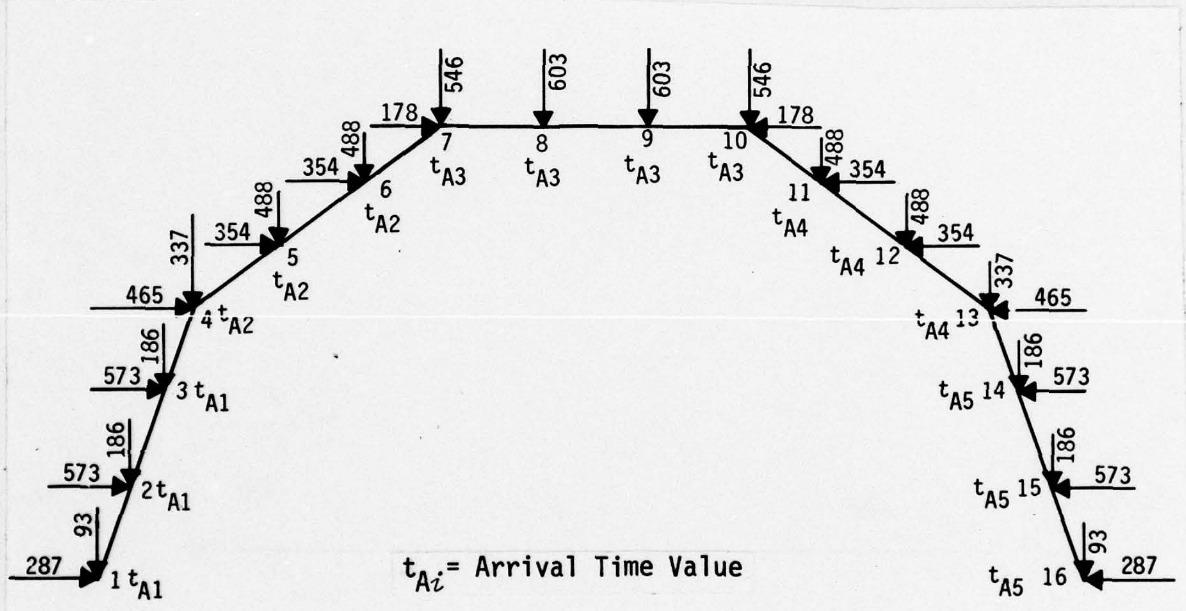


Figure 39. Polygonal Frame - Dynamic Loading

The indicated loads are in units of pounds.

4.4.2 Finite Element Model

The same 15 3-D beam elements used in problem 4.3.4 were used for this dynamic case. Also, the assignment of nodes and beam elements for this problem was the same as for problem 4.3.4.

4.4.3 Input Data - Polygonal Frame - Traveling Pressure Wave

```
HEADER=*POLY. FRAME TRAV. UNIF. LOAD 1000FPS 10 LBS./IN.
NUMNP=17,NELTYP=1,NF=10,NDYN=2,
IX(1,16,17)=1,1,1,1,1,1,
IX(2 15)=0,0,1,1,1,0,
XYZT(1)=
XYZT(2)=18.,56.
XYZT(3)=37.,113.,
XYZT(4)=55.,169.,
XYZT(5)=103.,204.,
XYZT(6)=151.,239.,
XYZT(7)=199.,274.,
XYZT(8)=258.,274.,
XYZT(9)=318.,274.,
XYZT(10)=377.,274.,
XYZT(11)=425.,239.,
XYZT(12)=473.,204.,
XYZT(13)=521.,169.,
XYZT(14)=539.,113.,
XYZT(15)=558.,56.,
XYZT(16)=576.,
XYZT(17)=0.,300..
NBEAM=15,BNMPC=1,BNEPC=1,
BMPC(1)=2.9E7,.3,7.339E-4,.289
BEPC(1)=10.6,,,.83,25.5,281.,
BEAM(1)=1,2,17,1,1
BEAM(2)=2,3,17,1,1
BEAM(3)=3,4,17,1,1
BEAM(4)=4,5,17,1,1
BEAM(5)=5,6,17,1,1
BEAM(6)=6,7,17,1,1
BEAM(7)=7,8,17,1,1
BEAM(8)=8,9,17,1,1
BEAM(9)=9,10,17,1,1
BEAM(10)=10,11,17,1,1
BEAM(11)=11,12,17,1,1
BEAM(12)=12,13,17,1,1
BEAM(13)=13,14,17,1,1
BEAM(14)=14,15,17,1,1
BEAM(15)=15,16,17,1,1
NFN=1,NAT=5,NT=5000,NOT=10,DT=.0002
NP(1,1)=1.1,287.
NP(1,2)=1.1,-93.
NP(2,1)=1.1,573.
NP(2,2)=1.1,-186.
NP(3,1)=1.1,573.
NP(3,2)=1.1,-186.
NP(4,1)=1.2,465.
```

Input Data - Polygonal Frame - Traveling Pressure Wave (concluded)

```
NP(4,2)=1.2,-337.
NP(5,1)=1.2,354.
NP(5,2)=1,2,-488.
NP(6,1)=1.2,354.
NP(6,2)=1,2,-488.
NP(7,1)=1,3,178.
NP(7,2)=1,3,-546.
NP(8,2)=1,3,-603.
NP(9,2)=1.3,-603.
NP(10,1)=1.3,-178.
NP(10,2)=1.3,-546.
NP(11,1)=1.4,-354.
NP(11,2)=1.4,-488.
NP(12,1)=1,4,-354.
NP(12,2)=1,4,-488.
NP(13,1)=1,4,-465.
NP(13,2)=1,4,-337.
NP(14,1)=1,5,-573.
NP(14,2)=1,5,-186.
NP(15,1)=1,5,-573.
NP(15,2)=1,5,-186.
NP(16,1)=1,5,-287.
NP(16,2)=1,5,-93.
AT(1)=0.,AT(2)=.0071,AT(3)=.02,AT(4)=.0339,AT(5)=.0434
NLP(1)=2,1.
T(1,1)=0.,T(1,2)=2.
F(1,1)=1.,F(1,2)=1.
KKK=2,
ICOMP(1,4.7.10.13,16)=1,2,3,6
KKKS=2
IS(2,1)=1.2,6,7,8,12
IS(2,4)=1.2,6,7,8,12
IS(2,7)=1.2,6,7,8,12
IS(2,10)=1.2.6,7,8,12
IS(2,13)=1,2,6,7,8,12
IS(2,15)=1.2,6,7,8,12
```

4.4.4 Results

The first part of the results give the first 10 eigenvalues and eigenvectors of the frame. Figure 40 shows the first three mode shapes.

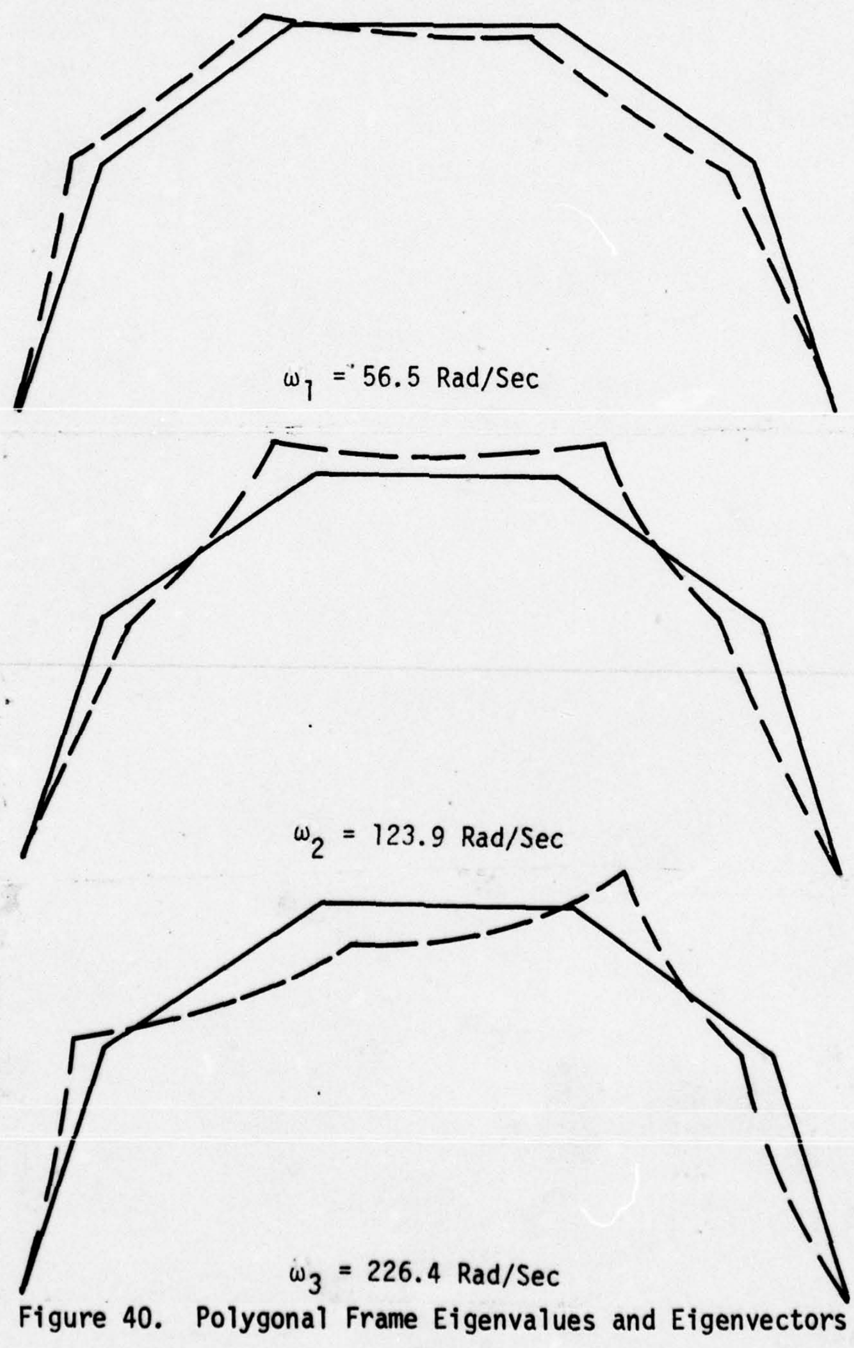


Figure 40. Polygonal Frame Eigenvalues and Eigenvectors

Time-history response curves for node 7 are shown in Figures 41 and 42. Components 1 and 2 refer to the x and y motion, respectively. The rotation response curves refer to z-axis rotation. The expected period of vibration for all of these curves is approximately equal to the period of the first mode of vibration of 0.1112 second.

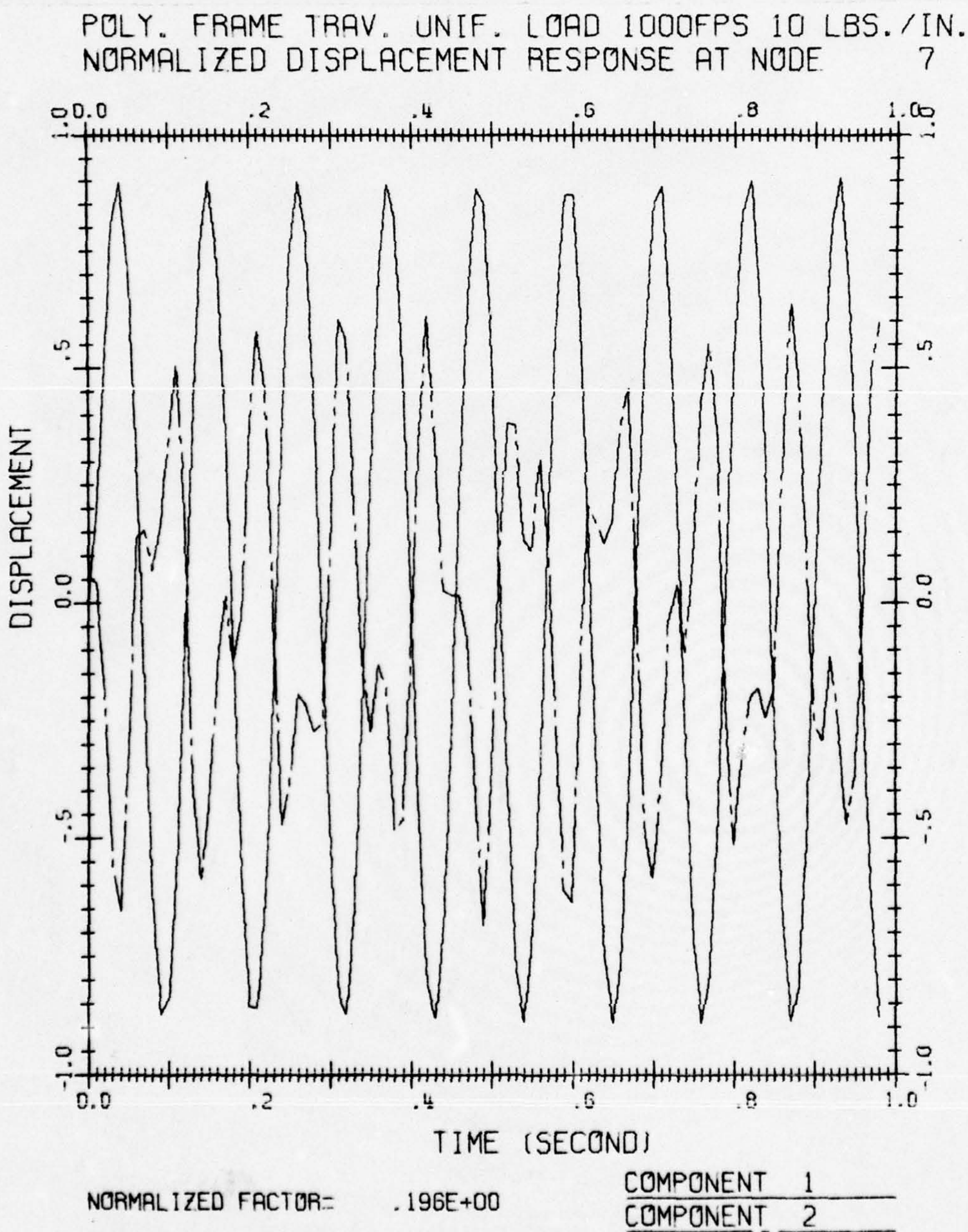


Figure 41. Displacement Response

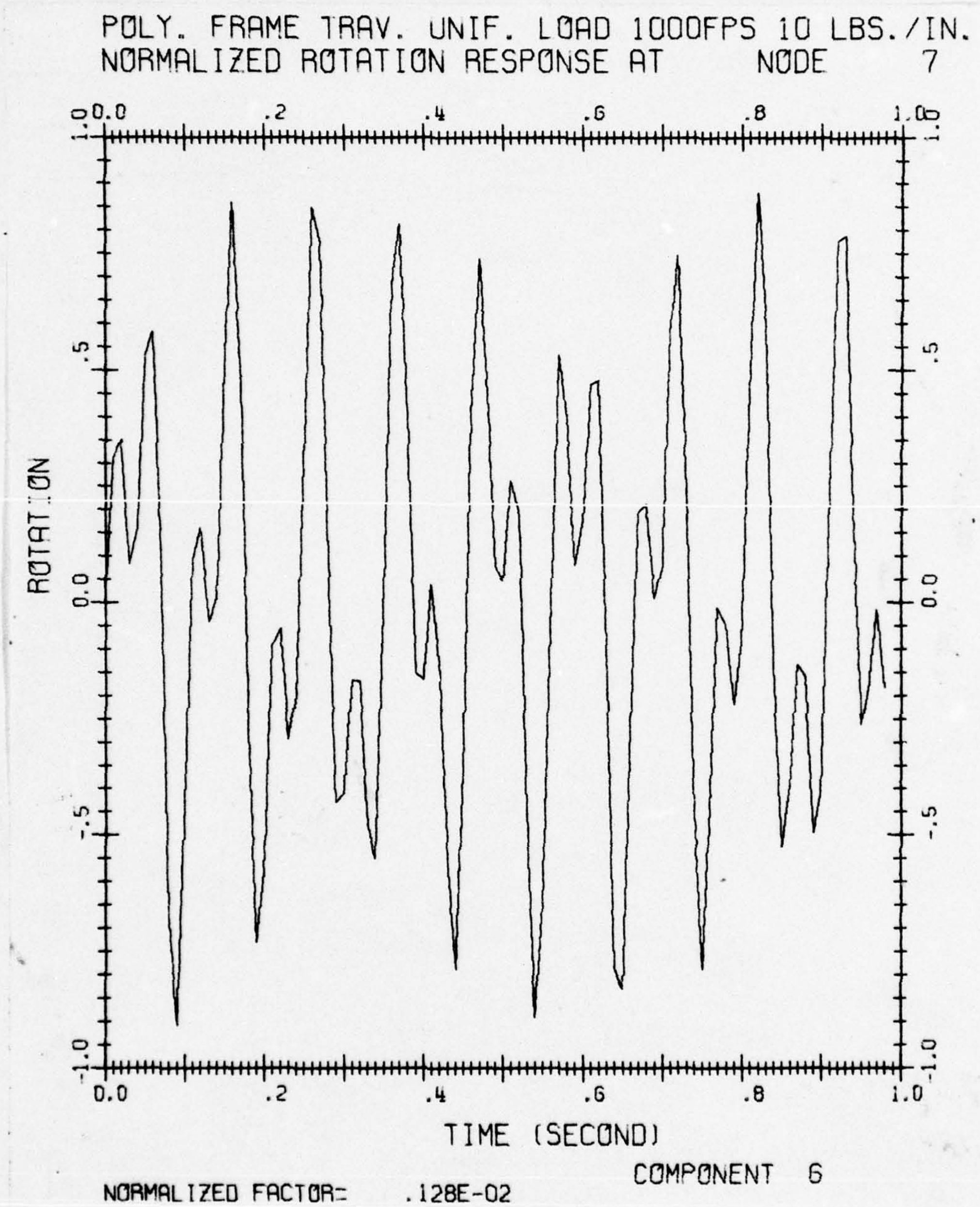


Figure 42. Rotation Response

For the time histories shown in Figure 43, component 1 is the axial force at node 7 and component 2 is the shear force at node 7. All of these components act on element 7.

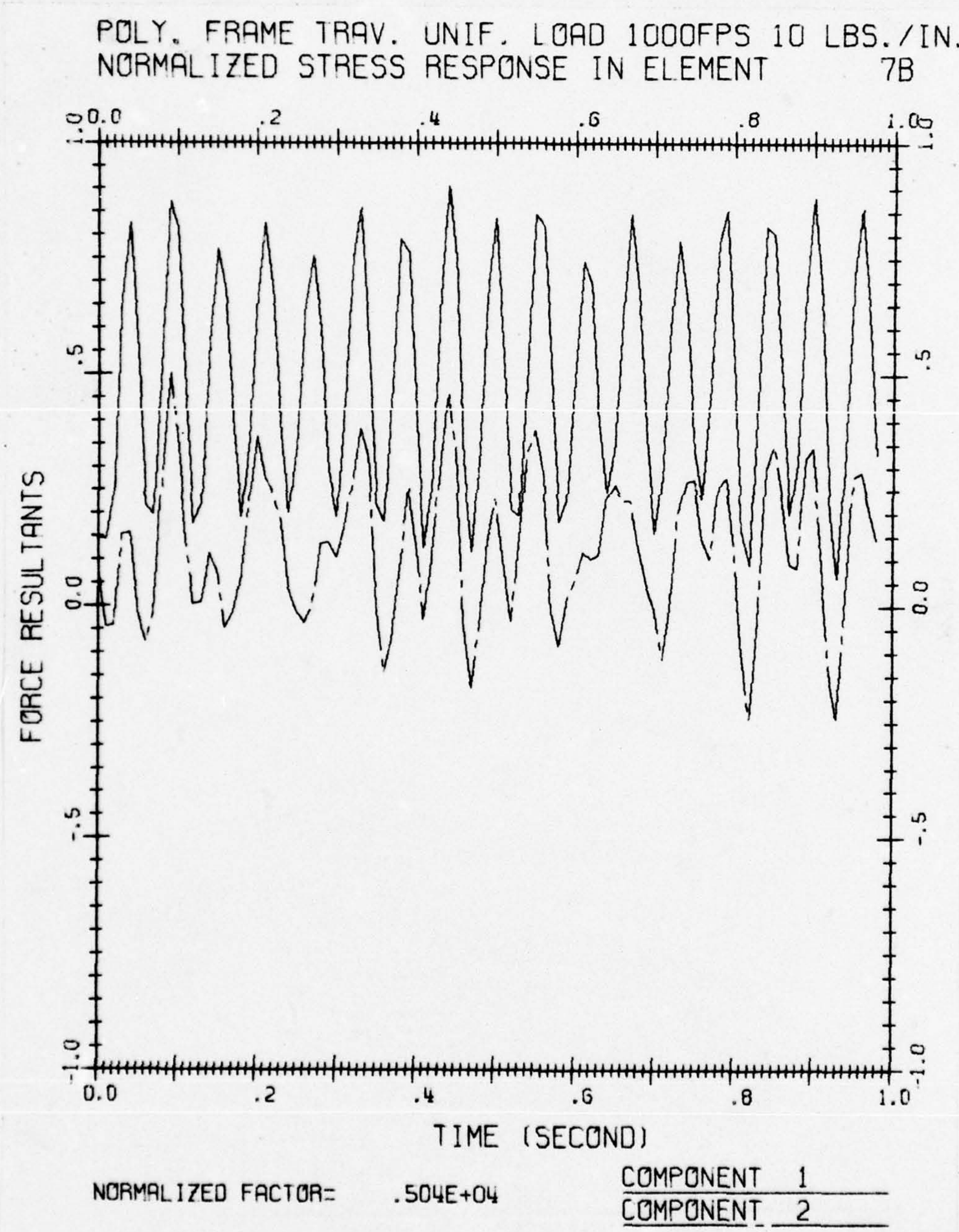


Figure 43. Force Response Element 7

4.5 Response-Time History of a Reinforced Concrete Polygonal Frame

4.5.1 Problem Description

A five-sided polygonal frame with geometry similar to the frames discussed in problems 4.3 and 4.4 was subjected to a traveling pressure wave. The frame was made up of members that were 2-foot sections of a reinforced concrete covered corrugated steel arch aircraft shelter. The cross-section is shown in Figure 44.

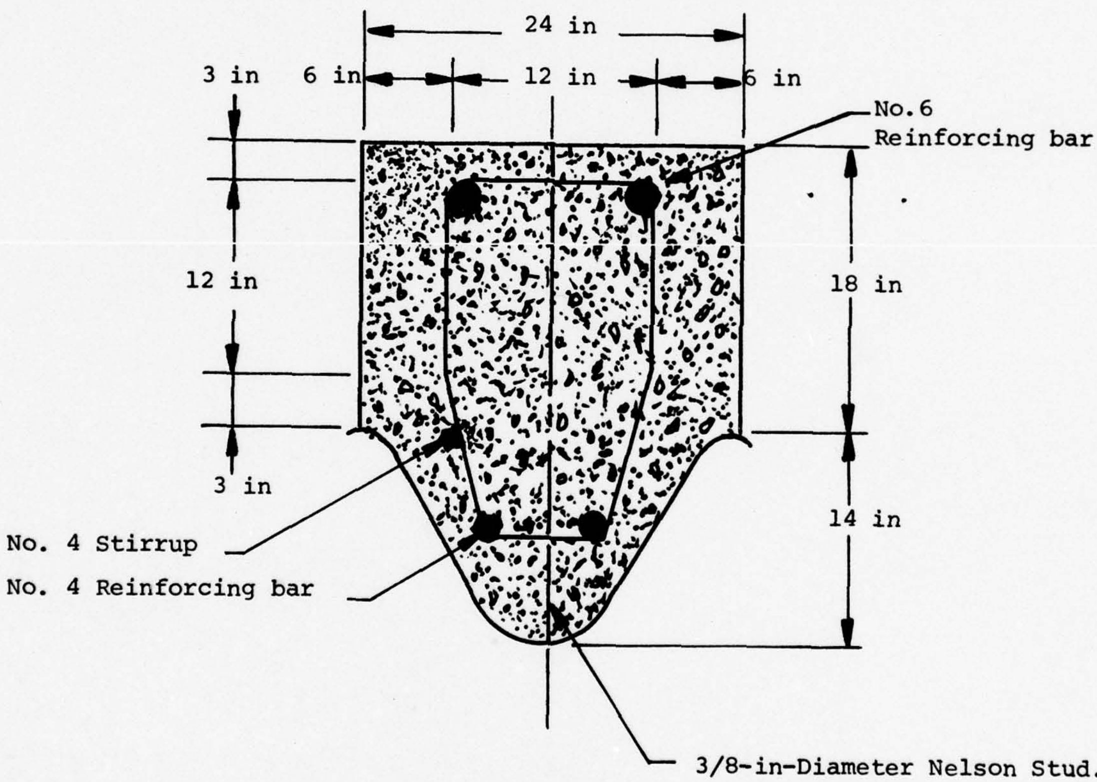


Figure 44. Shelter Section

For the analysis an equivalent reinforced concrete section was chosen by matching flexural rigidities of the uncracked sections. This section is shown in Figure 45.

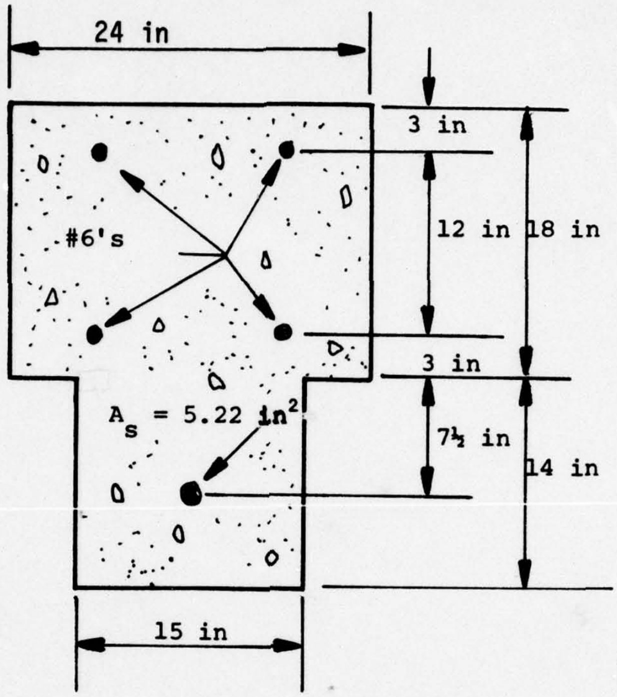


Figure 45. Equivalent Reinforced Concrete Section

Steel in the lower portion of the model with an area of 5.22 in^2 was selected to match the area of steel in the corrugated steel panel and was placed at a position which coincided with the center of gravity of the steel panel. It should also be noted that the area of concrete in the lower portion of the model was equal to the area of concrete in the steel panel.

The approximate moment of inertia of the shelter section cast in the corrugated steel panel was determined by transforming the reinforcing steel and panel steel into an equivalent amount of concrete. Two methods were used. The width of the cross-section was treated as 24 1/2-inch wide strips. Using this technique, the moment of inertia of an uncracked 2-foot wide section of the shelter was computed to be 56,034 in^4. The moment of inertia of the uncracked equivalent reinforced section (Figure 45) is 58,665 in^4. This is a difference of only 4.5 percent.

The method for selecting the equivalent stiffness of a concrete section to use in a dynamic analysis has previously been discussed. Using these procedures an effective stiffness of 36.189 in^4 was used, along with an area of 711.8 in^2, a torsional rigidity of 20,000 in^4 and a weak axis flexural rigidity of 20,000 in^4. It should be noted that the latter three values do not affect the results of this analysis.

The pressure wave used for the analysis was selected to model the free field overpressure data traces from the mixed company event at a range of 600 feet. The wave selected had a maximum pressure of 36.7 psi, a duration of 160 milliseconds and a velocity of 2000 ft/sec. The wave chosen is shown in Figure 46.

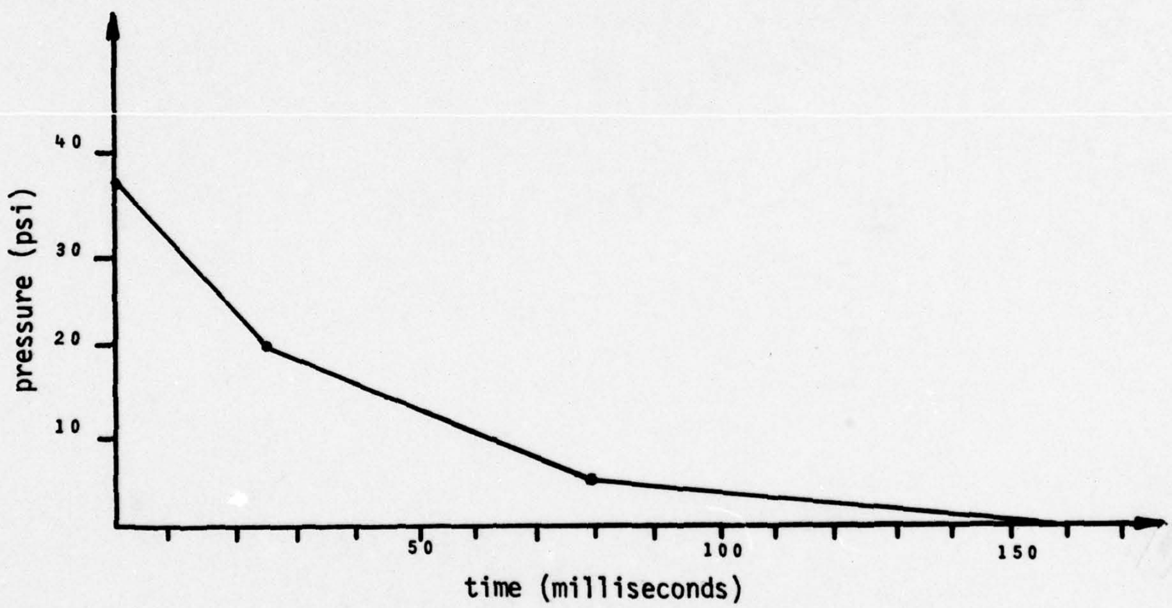


Figure 46. Pressure Wave

For the 2-foot wide section, the peak pressure of 36.7 psi was equivalent to a uniform load of 881 lb/in, which was replaced by

equivalent concentrated forces acting at 16 nodes. These equivalent forces are shown in Figure 47 and are also in pounds.

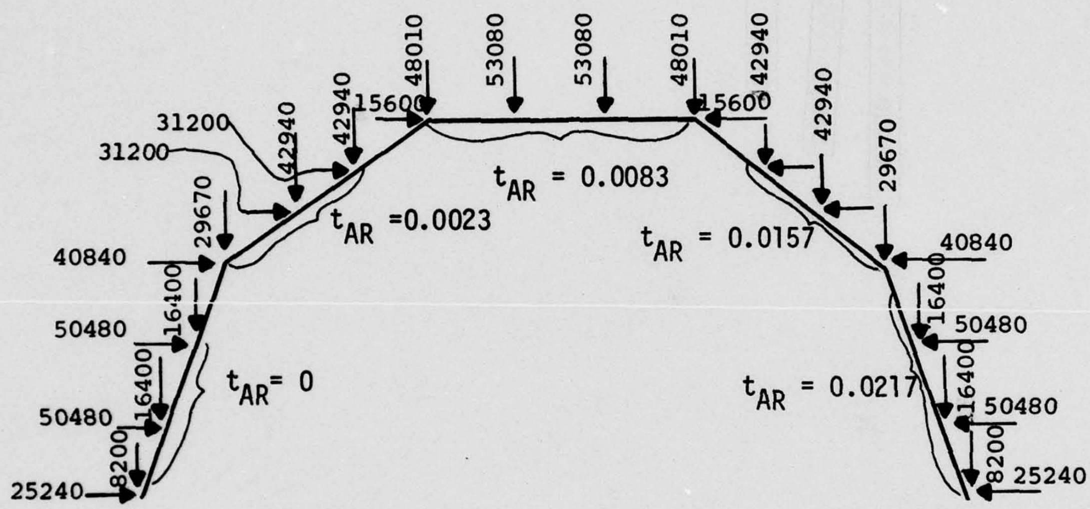


Figure 47. Equivalent Nodal Forces - Concrete Polygonal Frame

The arrival times in seconds, of the wave traveling at 2000 ft/sec are also indicated in the sketch.

4.5.2 Finite Element Model

The same 16 nodal points used in problems 4.3 and 4.4 were used for this analysis. Fifteen 3-D beam elements were used to model the five-sided polygonal frame.

4.5.3 Input Data - Concrete Polygonal Frame - Dynamic

```
HEADER=*POLY. FRAME MIXED COMPANY 600 FT. 2000 FPS
NUMNP=17,NELTYP=1,NF=10,NDYN=2,
IX(1,16,17)=1,1,1,1,1,1
IX(2 15)=0,0,1,1,1,0
XYZT(1)=
XYZT(2)=18.,56.
XYZT(3)=37.,113.
XYZT(4)=55.,169.
XYZT(5)=103.,204.
XYZT(6)=151.,239.
XYZT(7)=199.,274.
XYZT(8)=258.,274.
XYZT(9)=318.,274.
XYZT(10)=377.,274.
XYZT(11)=425.,239.
XYZT(12)=473.,204.
XYZT(13)=521.,169.
XYZT(14)=539.,113.
XYZT(15)=558.,56.
XYZT(16)=576.,
XYZT(17)=0.,300.,
NBEAM=15,BNMPC=1.BNEPC=1.
BMPC(1)=3.644E6,.17.2.1716E-4,.0839
BEPC(1)=711.8,,,20000.,20000.,36189.4
BEAM(1)=1.2,17,1,1
BEAM(2)=2,3,17,1,1
BEAM(3)=3.4.17.1,1
BEAM(4)=4,5,17,1,1
BEAM(5)=5,6,17.1,1
BEAM(6)=6,7,17,1,1
BEAM(7)=7,8,17,1,1
BEAM(8)=8,9,17,1,1
BEAM(9)=9.10,17.1,1
BEAM(10)=10,11.17,1,1
BEAM(11)=11,12,17,1,1
BEAM(12)=12,13,17,1,1
BEAM(13)=13,14,17,1,1
BEAM(14)=14,15,17,1,1
BEAM(15)=15,16,17,1,1
NFN=1,NAT=5,NT=200,NOT=2,DT=.001
NP(1,1)=1,1.25240.
NP(1,2)=1.1,-8200.
NP(2,1)=1.1,50480.
NP(2,2)=1.1,-16400.
NP(3,1)=1,1,50480.
NP(3,2)=1.1,-16400.
```

Input Data - Concrete Polygonal Frame - Dynamic (Concluded)

```
NP(4,1)=1,2,40840.
NP(4,2)=1,2,-29670.
NP(5,1)=1,2,31200.
NP(5,2)=1,2,-42940.
NP(6,1)=1,2,31200.
NP(6,2)=1,2,-42940.
NP(7,1)=1,3,15600.
NP(7,2)=1,3,-48010.
NP(8,2)=1,3,-53080.
NP(9,2)=1,3,-53080.
NP(10,1)=1,3,-15600.
NP(10,2)=1,3,-48010.
NP(11,1)=1,4,-31200.
NP(11,2)=1,4,-42940.
NP(12,1)=1,4,-31200.
NP(12,2)=1,4,-42940.
NP(13,1)=1,4,-40840.
NP(13,2)=1,4,-29670.
NP(14,1)=1,5,-50480.
NP(14,2)=1,5,-16400.
NP(15,1)=1,5,-50480.
NP(15,2)=1,5,-16400.
NP(16,1)=1,5,-25240.
NP(16,2)=1,5,-8200.
AT(1)=0,AT(2)=.0023,AT(3)=.0083,AT(4)=.0157,AT(5)=.0217
NLP(1)=5,1.
T(1,1)=0.,T(1,2)=.025,T(1,3)=.08,T(1,4)=.16,T(1,5)=.25
F(1,1)=1.,F(1,2)=.545,F(1,3)=.135,F(1,4)=0.,F(1,5)=0.
KKK=2,ISP=1
ICOMP(4,7,8,9)=1,2
KKKS=2
IS(2,1)=1,2,6,7,8,12
IS(2,4)=1,2,6,7,8,12
IS(2,7)=1,2,6,7,8,12
IS(2,10)=1,2,6,7,8,12
IS(2,13)=1,2,6,7,8,12
IS(2,15)=1,2,6,7,8,12
'
```

4.5.4 Results

The first part of the results gives the first 10 eigenvalues and mode shapes. Figure 48 shows the first three mode shapes and frequencies.

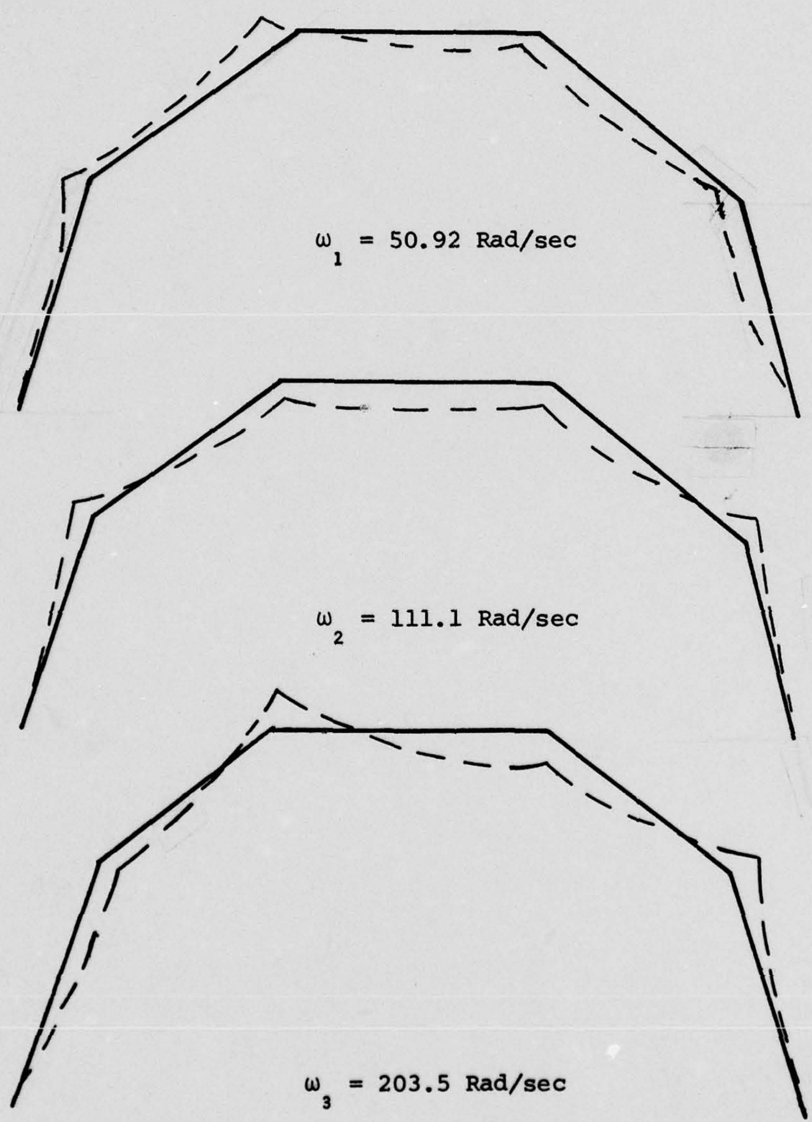


Figure 48. Concrete Polygonal Frame Eigenvalues and Eigenvectors

The first natural frequency of the reinforced concrete polygonal frame was 50.9 rad/sec.

The first natural frequency of the steel polygonal frame was 56.5 rad/sec. The natural frequency of a beam is given by

$$f_n = n^2 \alpha\sqrt{EI/A\lambda}$$

The members of the steel frame had properties: $E = 29 \times 10^6$ psi,

$I = 281.0$ in^4, $A = 10.6$ in^2 and $\lambda = 0.289$ lb/in^3.

The quantity under the radical is equal to

$$\sqrt{EI/A\lambda} = 5.158 \times 10^4$$

The members of the reinforced concrete frame had properties:

$E = 3.64 \times 10^6$ psi, $I = 36{,}189$ in^4, $A = 711.8$ in^2 and

$\lambda = 0.0839$ lb/in^3.

The quantity under the radical is equal to

$$\sqrt{EI/A\lambda} = 4.696 \times 10^4$$

The results of problems 4.4 and 4.5 are shown to be consistent since

$\omega_{st}/\omega_{conc} = 1.11$

and

$$\frac{\sqrt{EI/A\lambda}\ st}{\sqrt{EI/A\lambda}\ conc} = 1.10$$

As a further example of the results consider the displacement response history at node 7 as seen in Figure 49. Components 1 and 2 correspond to the horizontal and vertical displacements, respectively. The horizontal displacement has a period of 0.125 second which compares well with the expected period (from first node) of 0.123 second.

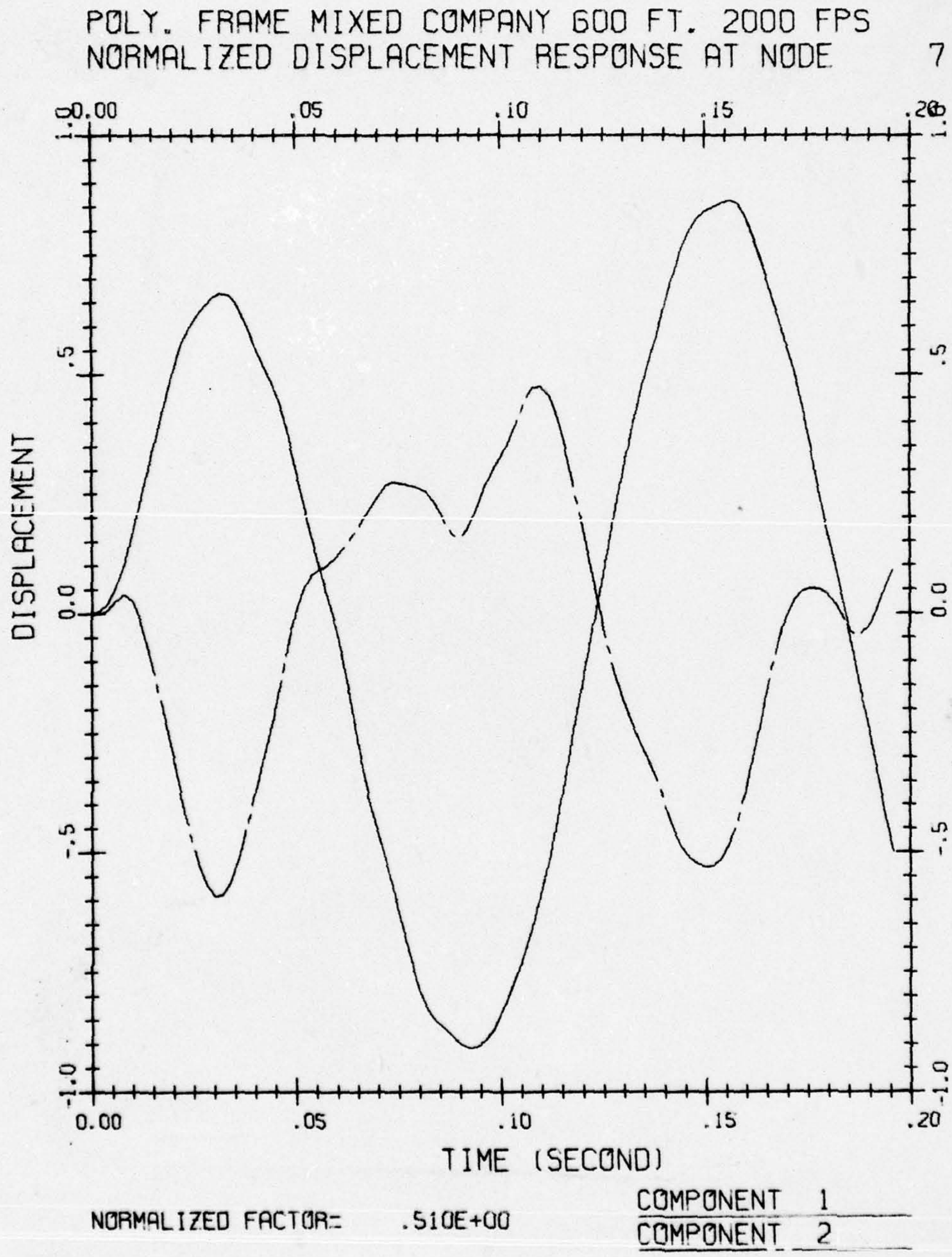


Figure 49. Displacement Response History
Concrete Polygonal Frame

5. Plates

5.1 Square Plates

5.1.1 Load Functions

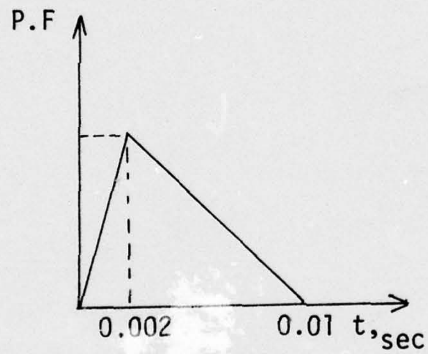
A simply supported square plate is subjected to the following loads:

Case 1. Static point load at center

Case 2. Dynamic point load at center with the time history shown in Figure 50

Case 3. Static uniform pressure

Case 4. Dynamic uniform pressure with the time history shown in Figure 50



Load - Time History

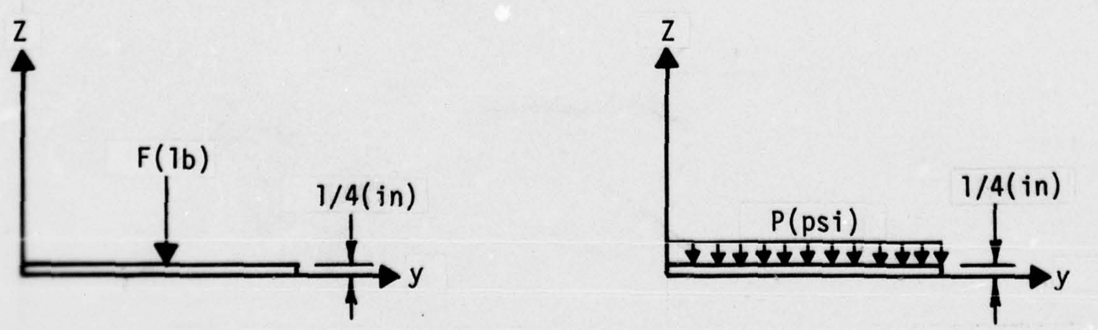


Figure 50. Square Plate - Static and Dynamic Loading (Continued)

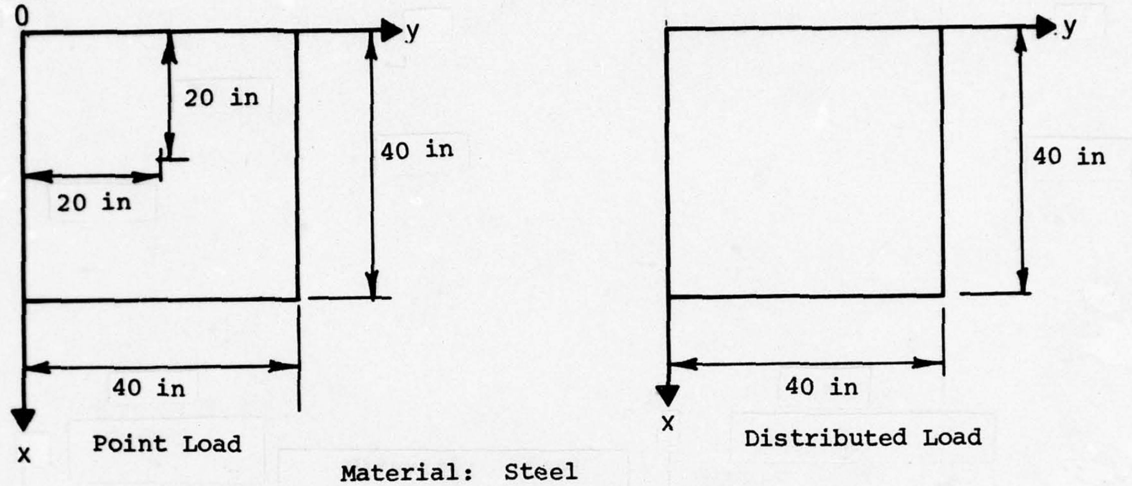


Figure 50. Square Plate - Static and Dynamic Loading (Concluded).

5.1.2 Finite Element Model

Since this plate is symmetrical with respect to the x-axis and the y-axis with origin at the center, one-quarter of the plate is sufficient for this analysis. Four thin plate elements were used with the location of nodes and elements shown in Figure 51.

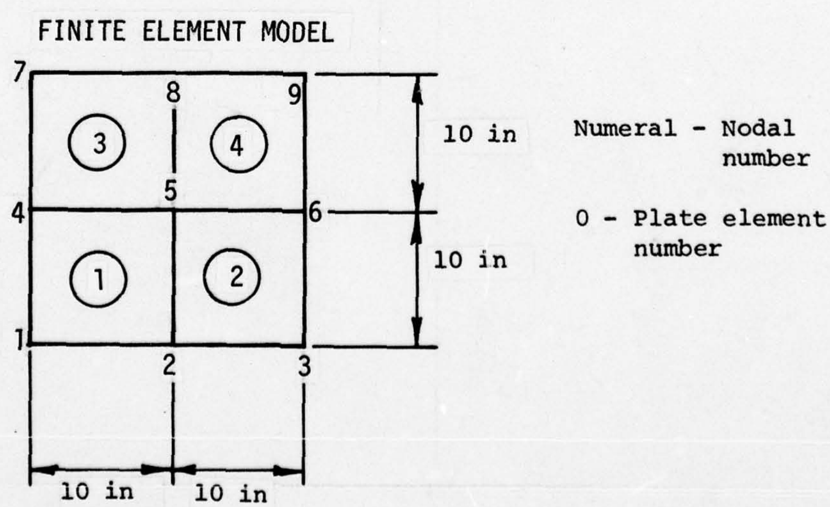


Figure 51. Element Assignment - Square Plate

5.1.3 Input Data - Case 1 - Static - Point Load at Center

```
HEADER=*STATIC ANALYSIS OF SIMPLY SUPPORTED RECTANGULAR PLATE
NUMNP=9,NFLTYP=1,LL=1,
IX(1)=0,1,1,0,1,1
IX(2)=0,0,0,0,1,1
IX(3)=0,0,0,1,1,1
IX(4)=0,1,1,0,0,1
IX(5)=0,0,0,0,0,1
IX(6)=0,0,0,1,0,1
IX(7)=1,1,1,0,0,1
IX(8)=1,0,1,0,0,1
IX(9)=1,0,1,1,0,1
XYZT(1)=20.
XYZT(2)=20.,10.,
XYZT(3)=20.,20.
XYZT(4)=10.,
XYZT(5)=10.,10.,
XYZT(6)=10.,20.,
XYZT(7)=
XYZT(8)=,10.
XYZT(9)=,20.
NPLATE=4,PNDM=1.
PMPI(1)=.0007346,,,,3.375E7,1.125E7,,3.375E7,,1.125E7
PLATE(1 4)=.25
IPLATE(1)=1,2,5,4,,1
IPLATE(2)=2,3,6,5,,1
IPLATE(3)=4,5,8,7,,1
IPLATE(4)=5,6,9,8,,1
CLMD(3,1)=,,-25.
'
```

5.1.4 Input Data - Case 2 - Dynamic - Point Load at Center

```
HEADER=*DYNAMIC ANALYSIS OF A SIMPLY SUPPORTED PLATE
NUMNP=9,NELTYP=1,NF=10,NDYN=2,
IX(1)=0,1,1,0,1,1,         XYZT(1)=20.,
IX(2)=0,0,0,0,1,1,         XYZT(2)=20.,10.,
IX(3)=0,0,0,1,1,1,         XYZT(3)=20.,20.,
IX(4)=0,1,1,0,0,1,         XYZT(4)=10.,
IX(5)=0,0,0,0,0,1,         XYZT(5)=10.,10.,
IX(6)=0,0,0,1,0,1,         XYZT(6)=10.,20.,
IX(7)=1,1,1,0,0,1,         XYZT(7)=
IX(8)=1,0,1,0,0,1,         XYZT(8)=0.,10.,
IX(9)=1,0,1,1,0,1,         XYZT(9)=0.,20.,
NPLATE=4,PNDM=1,
PMPI(1)=.0007346,,,,3.375E7,1.125E7,,3.375E7,,1.125E7,
PLATE(1 4)=.25,
IPLATE(1)=1,2,5,4,,1,
IPLATE(2)=2,3,6,5,,1,
IPLATE(3)=4,5,8,7,,1,
IPLATE(4)=5,6,9,8,,1,
IFPR=1,NFN=1,NT=1000,NOT=10,DT=.0001
NP(3,3)=1,,1.0,
NLP(1)=4,-25.
T(1,1)=0.,T(1,2)=.002,T(1,3)=.01,T(1,4)=1.0
F(1,1)=0.,F(1,2)=1.0,F(1,3)=0.,F(1,4)=0.,
KKK=2
ICOMP(1 9)=1,2,3,4,5,6
KKKS=2
IS(6,1)=1,2,3,4,5,6
IS(6,2)=1,2,3,4,5,6
IS(6,3)=1,2,3,4,5,6
IS(6,4)=1,2,3,4,5,6
,
```

5.1.5 Input Data - Case 3 - Static Uniform Pressure

```
HEADER=*STATIC ANALYSIS OF SIMPLY SUPPORTED RECTANGULAR  PLATE
NUMNP=9,NELTYP=1,LL=1,
IX(1)=0,1,1,0,1,1
IX(2)=0,0,0,0,1,1
IX(3)=0,0,0,1,1,1
IX(4)=0,1,1,0,0,1
IX(5)=0,0,0,0,0,1
IX(6)=0,0,0,1,0,1
IX(7)=1,1,1,0,0,1
IX(8)=1,0,1,0,0,1
IX(9)=1,0,1,1,0,1
XYZT(1)=20.
XYZT(2)=20.,10.,
XYZT(3)=20.,20.
XYZT(4)=10.,
XYZT(5)=10.,10.,
XYZT(6)=10.,20.,
XYZT(7)=
XYZT(8)=,10.
XYZT(9)=,20.
NPLATE=4,PNDM=1.
PELML=1.
PMPI(1)=.0007346,,,,3.375E7,1.125E7,,3.375E7,,1.125E7
PLATE(1 4)=.25,-25.
IPLATE(1)=1,2,5,4,,1
IPLATE(2)=2,3,6,5,,1
IPLATE(3)=4,5,8,7,,1
IPLATE(4)=5,6,9,8,,1
ELM(1)=1.,
'
```

5.1.6 Input Data - Case 4 - Dynamic - Uniform Pressure

```
HEADER=*DYNAMIC ANALYSIS OF A SIMPLY SUPPORTED PLATE
NUMNP=9,NELTYP=1,NF=10,NDYN=2,
IX(1)=0,1,1,0,1,1,          XYZT(1)=20.,
IX(2)=0,0,0,0,1,1,          XYZT(2)=20.,10.,
IX(3)=0,0,0,1,1,1,          XYZT(3)=20.,20.,
IX(4)=0,1,1,0,0,1,          XYZT(4)=10.,
IX(5)=0,0,0,0,0,1,          XYZT(5)=10.,10.,
IX(6)=0,0,0,1,0,1,          XYZT(6)=10.,20.,
IX(7)=1,1,1,0,0,1,          XYZT(7)=
IX(8)=1,0,1,0,0,1,          XYZT(8)=0.,10.,
IX(9)=1,0,1,1,0,1,          XYZT(9)=0.,20.,
NPLATE=4,PNDM=1,
PMPI(1)=.0007346,,,,3.375E7,1.125E7,,3.375E7,,1.125E7,
PLATE(1 4)=.25,
IPLATE(1)=1,2,5,4,,1
IPLATE(2)=2,3,6,5,,1
IPLATE(3)=4,5,8,7,,1
IPLATE(4)=5,6,9,8,,1
IFPR=1,NFN=1,NT=1000,NOT=10,DT=.0001
NP(1,3)=1,,-62.5
NP(2,3)=1,,-125.
NP(3,3)=1,,-62.5
NP(4,3)=1,,-125.
NP(5,3)=1,,-250.
NP(6,3)=1,,-125.
NP(7,3)=1,,-62.5
NP(8,3)=1,,-125.
NP(9,3)=1,,-62.5
NLP(1)=4,1.
T(1,1)=0.,T(1,2)=.002,T(1,3)=.01,T(1,4)=1.0
F(1,1)=0.,F(1,2)=1.0,F(1,3)=0.,F(1,4)=0.
KKK=2
ICOMP(1 9)=1,2,3,4,5,6
KKKS=2
IS(6,1)=1,2,3,4,5,6
IS(6,2)=1,2,3,4,5,6
IS(6,3)=1,2,3,4,5,6
IS(6,4)=1,2,3,4,5,6
,
```

5.1.7 Results

Case 1 - Static

	SAP IV	Thin Plate Theory
Maximum deflection (at center)	-0.3990×10^{-1} in	-0.4223×10^{-1} in [4]
Bending moment at x = 15 in, y = 15 in	$M_{xx} = M_{yy} = -1.136 \times 10$ lb-in (Resultant in Element 2)	$M_{xx} = M_{yy} = -0.9831 \times 10$ lb-in [4]

Case 3 - Static

	SAP IV	Thin Plate Theory
Maximum deflection (at center)	-5.2135 in	-6.0484 in [5]
Maximum bending moment	1481 lb-in (Resultant in Element 2)	1916 lb-in [5] (at center)

Fundamental Frequency for Symmetric Model (rad/sec)

Mode Number	SAP IV	Thin Plate Theory[6]
1	0.1936×10^3	0.1908×10^3
2	0.9469×10^3	0.9539×10^3
3	1.358×10^3	1.717×10^3

Displacement - Time Histories

The response of the center of the plate for the two dynamic load functions is given in Figures 52 and 53.

---

[4] Timoshenko, S., and Woinowsky-Krieger, S., Theory of Plates and Shells, Page 143-149.

[5] Szilard, Rudolph, Theory and Analysis of Plates, page 650.

[6] Clark, S. K., Dynamics of Continuous Elements, page 172.

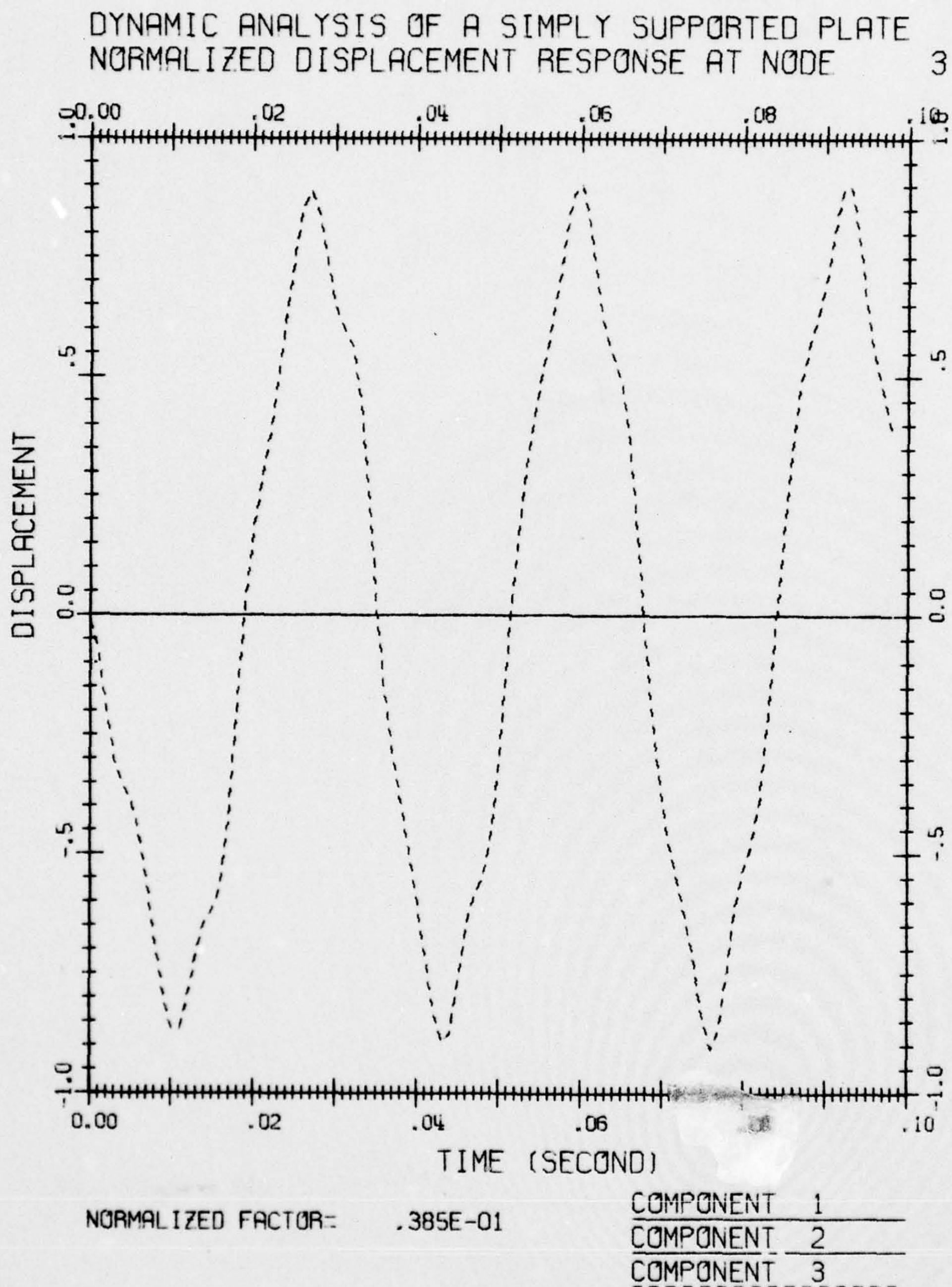


Figure 52. Nodal Displacement of Plate Center - Point Load

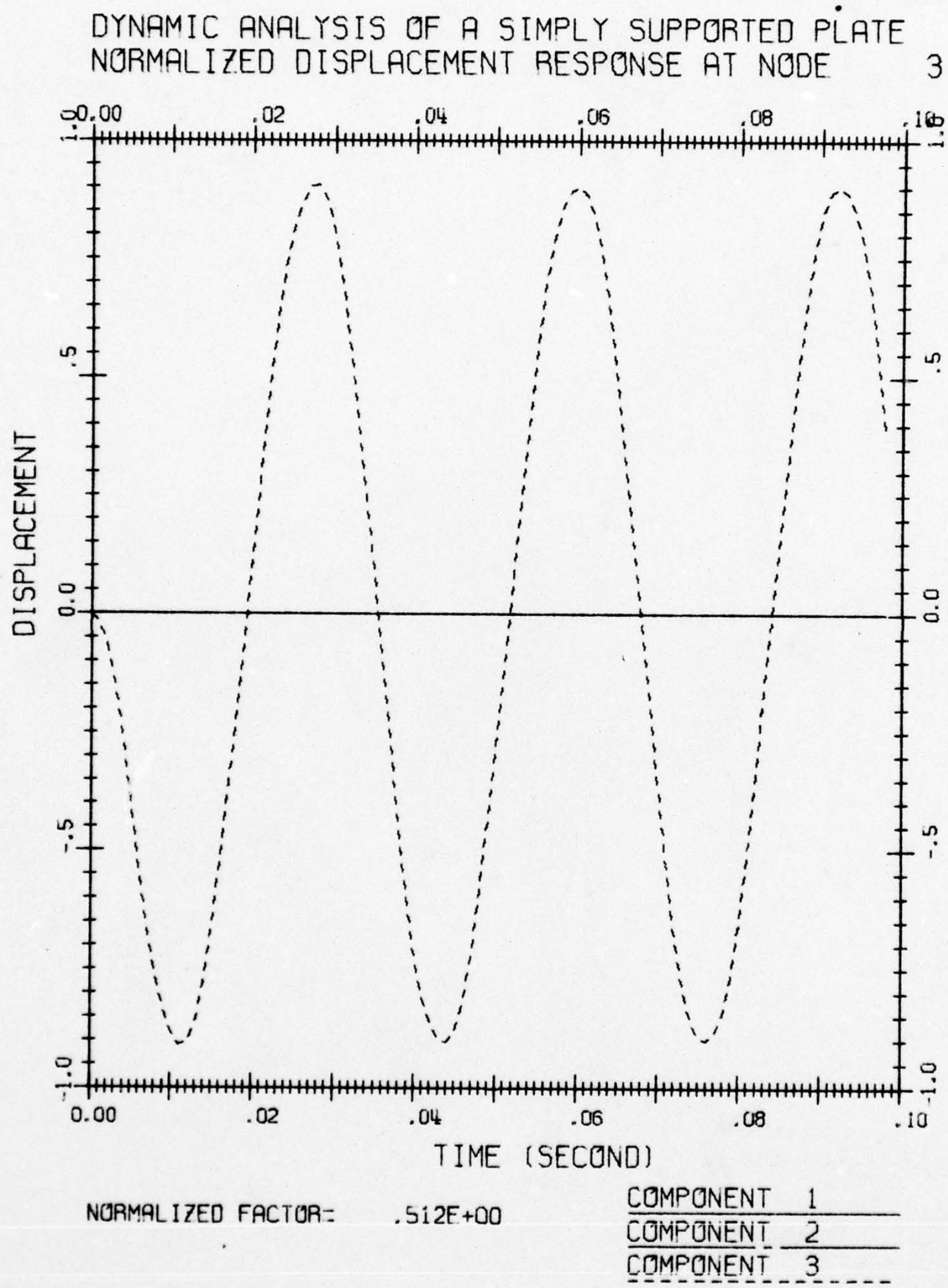


Figure 53. Nodal Displacement of Plate Center - Uniform Pressure

5.2 Square Plate with Two Reinforcing Ribs

5.2.1 Load Functions

A simply supported square plate with two reinforcing ribs (Figure 54) is subjected to the same loads as problem 5.1.

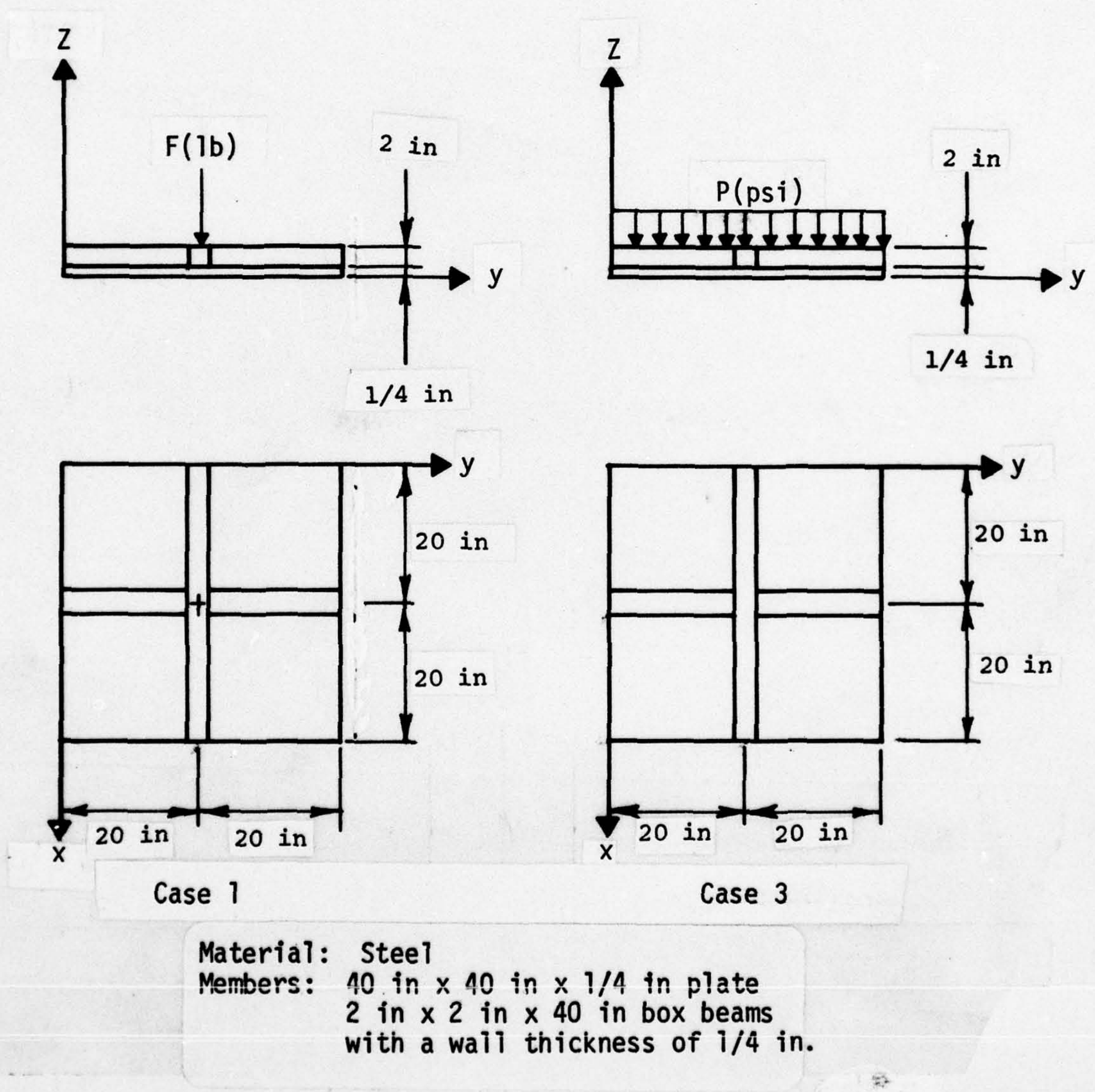


Figure 54. Square Plate with Two Reinforcing Ribs

5.2.2 Finite Element Model

Due to symmetry, a quarter of the plate is considered for this analysis. A group of four thin plate elements and four 3-D beam elements is used with the location of nodes and the elements shown in Figure 55.

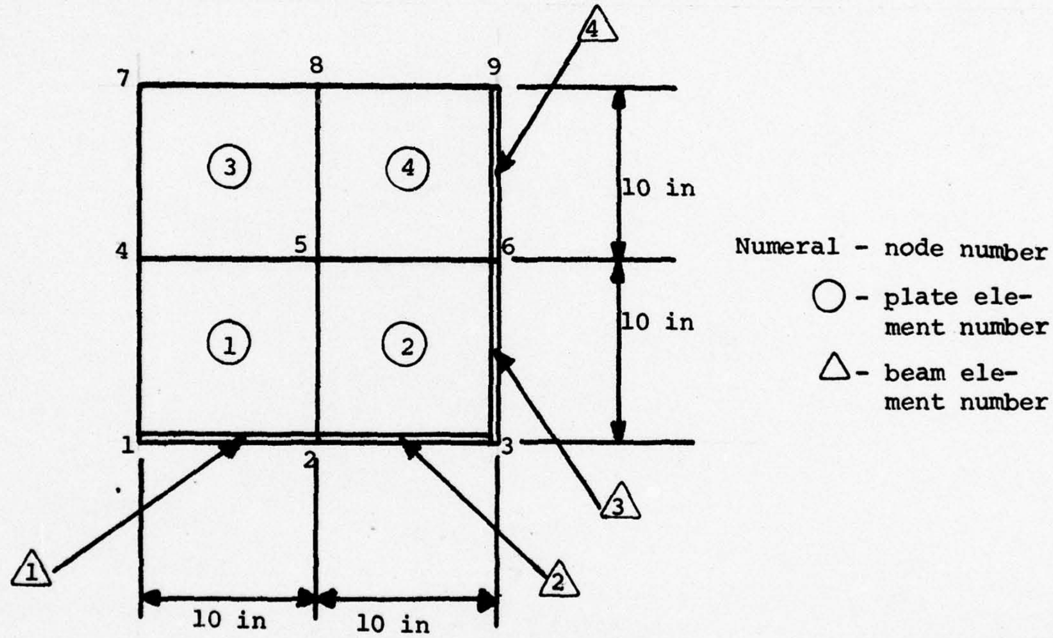


Figure 55. Element Assignment Two-Ribbed Plate

5.2.3 Input Data - Case 1 - Static Point Load - at Center

```
HEADER=*STATIC PLATE WITH REINFORCING RIBS
NUMNP=9,NFLTYP=2,LL=1
IX(1)=0,1,1,0,1,1,
IX(2)=0,0,0,0,1,1,
IX(3)=0,0,0,1,1,1,
IX(4)=0,1,1,0,0,1,
IX(5)=0,0,0,0,0,1,
IX(6)=0,0,0,1,0,1,
IX(7)=1,1,1,0,0,1,
IX(8)=1,0,1,0,0,1,
IX(9)=1,0,1,1,0,1,
XYZT(1)=20.
XYZT(2)=20.,10.,
XYZT(3)=20.,20.,
XYZT(4)=10.,
XYZT(5)=10.,10.,
XYZT(6)=10.,20.,
XYZT(7)=,
XYZT(8)=,10.,
XYZT(9)=,20.,
NBEAM=4,BNEPC=1,BNMPC=1,
BMPC(1)=3.E7,.333,.0007346
BEPC(1)=.795,,,.0395,.383,.383
BEAM(1)=1,2,4,1,1,
BEAM(2)=2,3,4,1,1,
BEAM(3)=3,6,4,1,1,
BEAM(4)=5,9,4,1,1,
NPLATE=4,PNDM=1,
PMPI(1)=.0007346,,,,3.375E7,1.125E7,,3.375E7,,1.125E7
PLATE(1 4)=.25
IPLATE(1)=1,2,5,4,,1
IPLATE(2)=2,3,6,5,,1
IPLATE(3)=4,5,8,7,,1
IPLATE(4)=5,6,9,8,,1
CLMD(3,1)=,,-25.
,
```

5.2.4 Input Data - Case 2 - Dynamic Point Load at Center

```
HEADER=*DYNAMIC ANALYSIS OF A SIMPLY-SUPPORTED PLATE W 2 REIN. RIB*
NUMNP=9,NELTYP=2,NF=10,NDYN=2
IX(1)=0,1,1,0,1,1,     XYZT(1)=20.
IX(2)=0,0,0,0,1,1,     XYZT(2)=20.,10.,
IX(3)=0,0,0,1,1,1,     XYZT(3)=20.,20.,
IX(4)=0,1,1,0,0,1,     XYZT(4)=10.,
IX(5)=0,0,0,0,0,1,     XYZT(5)=10.,10.,
IX(6)=0,0,0,1,0,1,     XYZT(6)=10.,20.,
IX(7)=1,1,1,0,0,1,     XYZT(7)=
IX(8)=1,0,1,0,0,1,     XYZT(8)=0.,10.,
IX(9)=1,0,1,1,0,1,     XYZT(9)=0.,20.,
NBEAM=4,BNEPC=1,BNMPC=1,
BMPC(1)=3.E7,.333,.0007346
BEPC(1)=.795,,,.0395,.383,.383
BEAM(1)=1,2,4,1,1
BEAM(2)=2,3,4,1,1
BEAM(3)=3,6,4,1,1
BEAM(4)=6,9,4,1,1
NPLATE=4,PNDM=1
PMPI(1)=.0007346,,,,3.375E7,1.125E7,,3.375E7,,1.125E7
PLATE(1 4)=.25
IPLATE(1)=1,2,5,4,,1
IPLATE(2)=2,3,6,5,,1
IPLATE(3)=4,5,8,7,,1
IPLATE(4)=5,6,9,8,,1
IFPR=1,NFN=1,NT=1000,NOT=10,DT=.0001
NP(3,3)=1.,1.
NLP(1)=4,-25.
T(1,1)=0.,T(1,2)=.002,T(1,3)=.01,T(1,4)=1.
F(1,1)=0.,F(1,2)=1.,F(1,3)=0.,F(1,4)=0.
KKK=2
ICOMP(3,5)=3
KKKS=2
IS(2,2)=1,2,3,4,5,6,7,8,9,10,11,12
IS(6,2)=1,2,3,4,5,6
,
```

5.2.5 Input Data - Case 3 - Static Uniform Pressure

```
HEADER=*STATIC PLATE WITH REINFORCING RIBS
NUMNP=9,NELTYP=2,LL=1
IX(1)=0,1,1,0,1,1,
IX(2)=0,0,0,0,1,1,
IX(3)=0,0,0,1,1,1,
IX(4)=0,1,1,0,0,1,
IX(5)=0,0,0,0,0,1,
IX(6)=0,0,0,1,0,1,
IX(7)=1,1,1,0,0,1,
IX(8)=1,0,1,0,0,1,
IX(9)=1,0,1,1,0,1,
XYZT(1)=20.
XYZT(2)=20.,10.,
XYZT(3)=20.,20.,
XYZT(4)=10.,
XYZT(5)=10.,10.,
XYZT(6)=10.,20.,
XYZT(7)=,
XYZT(8)=,10.,
XYZT(9)=,20.,
NBEAM=8,BNEPC=2,BNMPC=1,
BMPC(1)=3.E7,.333,.0007346
BEPC(1)=.795,,,.0395,.383,.383
BEPC(2)=1.59,,,.079,.766,.766
BEAM(1)=1,2,4,1,1,,,,,,,,1
BEAM(3)=3,6,4,1,1,,,,,,,,3
BEAM(5)=2,5,7,1,2,,,,,,,,3
BEAM(7)=4,5,7,1,2,,,,,,,,1
BEAM(8)=5,6,7,1,2,
NPLATE=4,PNDM=1
PMPI(1)=.0007346,,,,3.375E7,1.125E7,,3.375E7,,1.125E7,
IPLATE(1)=1,2,5,4,,1,1
PLATE(1 4)=.25
IPLATE(1)=1,2,5,4,,1,1
IPLATE(3)=4,5,8,7,,1,1
IPLATE(4)=5,6,9,8,,1
CLMD(3,1)=,,-25.,
,
```

5.2.6 Input Data - Case 4 - Dynamic - Uniform Pressure

```
HEADER=*DYNAMIC ANALYSIS OF A SIMPLY-SUPPORTED PLATE WITH 2 REIN
NUMNP=9,NELTYP=2,NF=10,NDYN=2,
IX(1)=0,1,1,0,1,1,          XYZT(1)=20.,
IX(2)=0,0,0,0,1,1,          XYZT(2)=20.,10.,
IX(3)=0,0,0,1,1,1,          XYZT(3)=20.,20.,
IX(4)=0,1,1,0,0,1,          XYZT(4)=10.,
IX(5)=0,0,0,0,0,1,          XYZT(5)=10.,10.,
IX(6)=0,0,0,1,0,1,          XYZT(6)=10.,20.,
IX(7)=1,1,1,0,0,1,          XYZT(7)=
IX(8)=1,0,1,0,0,1,          XYZT(8)=0.,10.,
IX(9)=1,0,1,1,0,1,          XYZT(9)=0.,20.,
NBEAM=4,BNMPC=1,BNEPC=1,
BMPC(1)=3.E7,.333,.0007346
BEPC(1)=.795,,,.0395,.383,.383
BEAM(1)=1,2,4,1,1
BEAM(2)=2,3,4,1,1
BEAM(3)=3,6,4,1,1
BEAM(4)=6,9,4,1,1
NPLATE=4,PNDM=1
PMPI(1)=.0007346,,,,3.375E7,1.125E7,,3.375E7,,1.125E7
PLATE(1 4)=.25
IPLATE(1)=1,2,5,4,,1
IPLATE(2)=2,3,6,5,,1
IPLATE(3)=4,5,8,7,,1
IPLATE(4)=5,6,9,8,,1
IFPR=1,NFN=1,NT=1000,NOT=10,DT=.0001
NP(1,3)=1,,-62.5
NP(2,3)=1,,-125.
NP(3,3)=1,,-62.5
NP(4,3)=1,,-125.
NP(5,3)=1,,-250.
NP(6,3)=1,,-125.
NP(7,3)=1,,-62.5
NP(8,3)=1,,-125.
NP(9,3)=1,,-62.5
NLP(1)=4,1.
T(1,1)=0.,T(1,2)=.002,T(1,3)=.01,T(1,4)=1.0
F(1,1)=0.,F(1,2)=1.0,F(1,3)=0.,F(1,4)=0.,
KKK=2
ICOMP(3,5)=3,
KKKS=2
IS(2,2)=1,2,3,4,5,6,7,8,9,10,11,12,
IS(6,2)=1,2,3,4,5,6,
'
```

5.2.7 Results

Case 1 - Static - Concentrated Load

Maximum Deflection (at center)	=	-2.695×10^{-2} in
Maximum Bending Moment (at center in beam element)	=	2.347×10^{2} lb-in

Case 3 - Static - Distributed Load

Maximum Deflection (at center)	=	-0.3774 in
Maximum Bending Moment (at center in beam element)	=	2.526×10^{4} lb-in

Plots of the deflection-time histories for the dynamic loads are given in Figures 56 and 57.

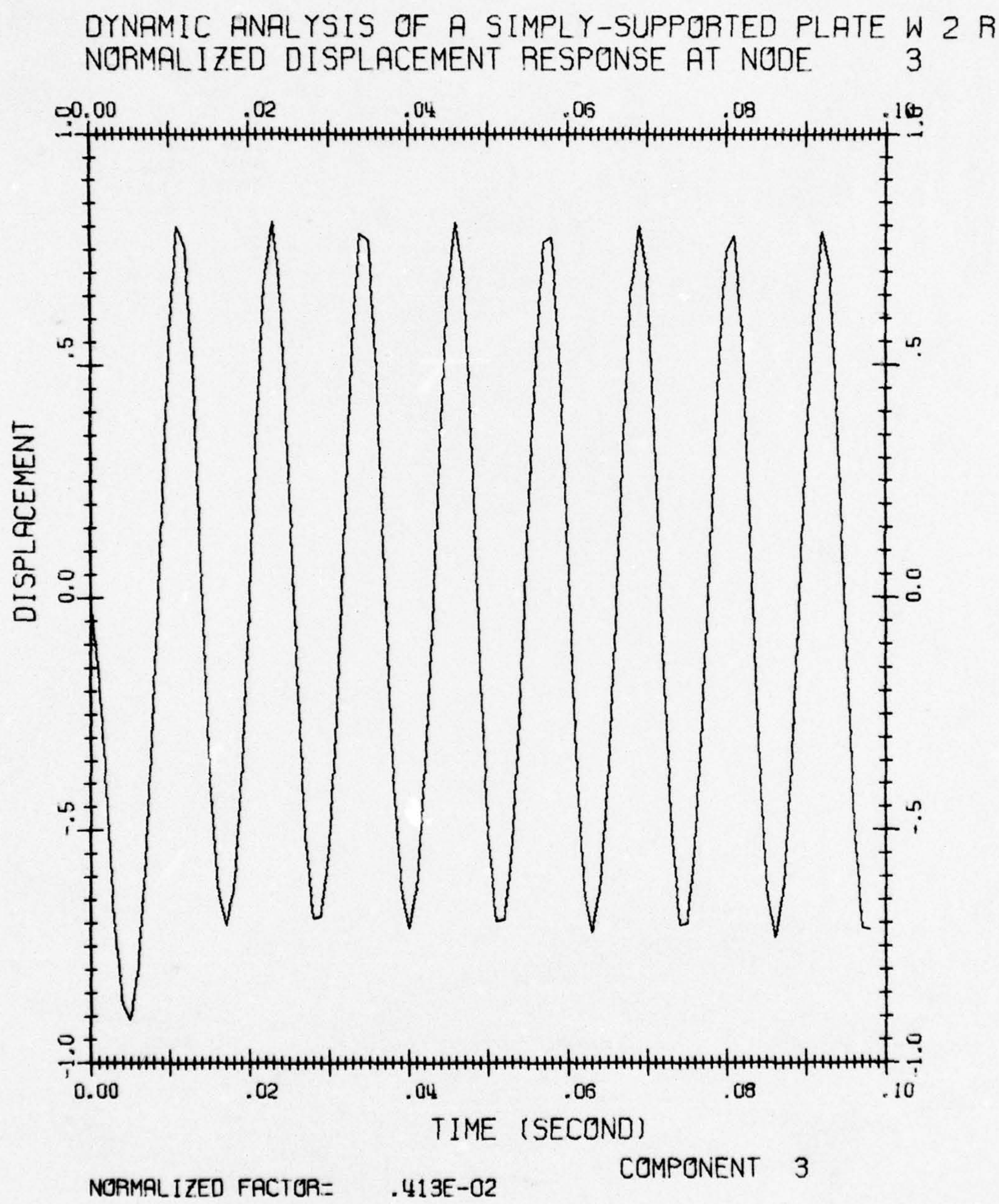


Figure 56. Time History of Plate Center - Point Load

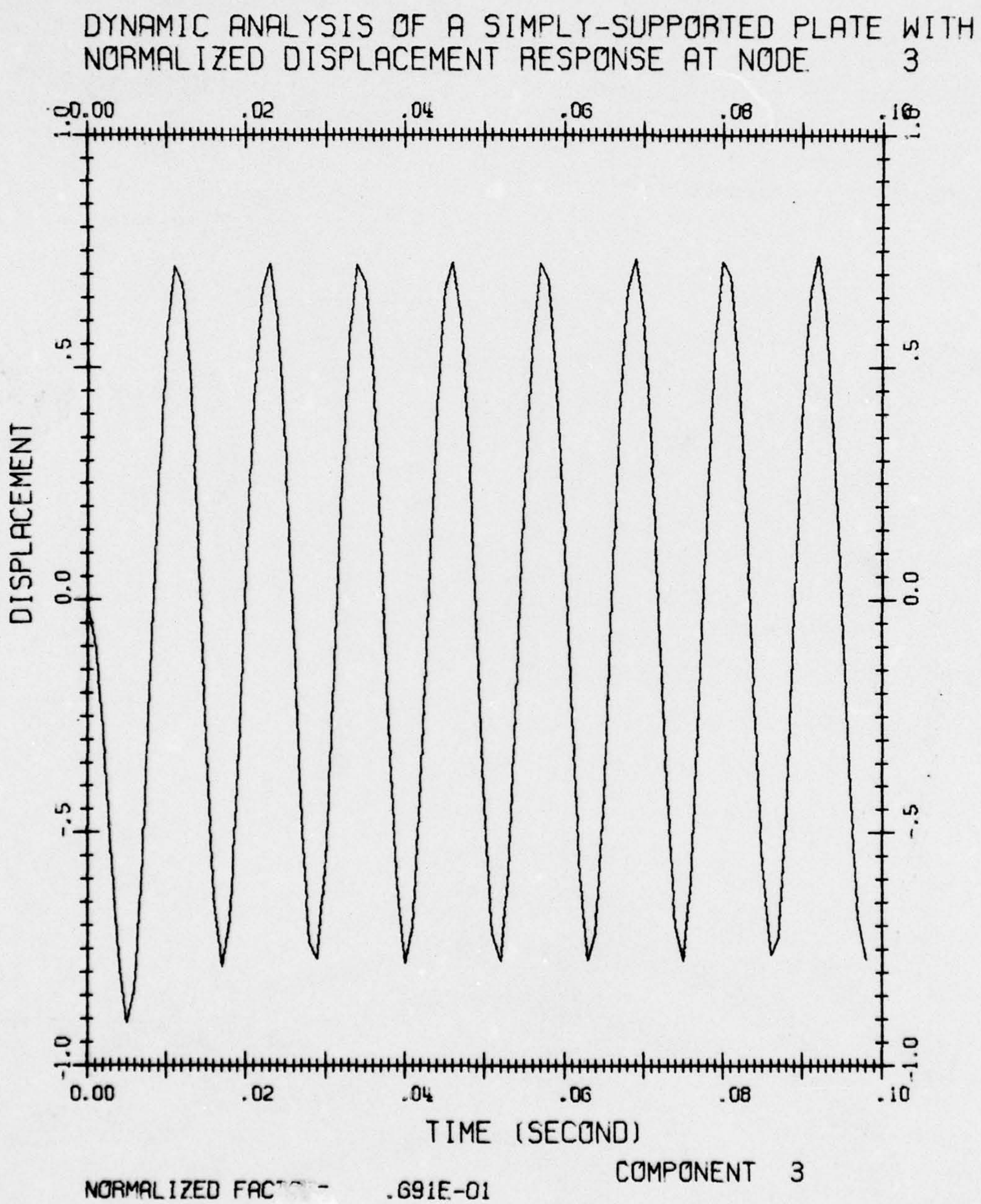
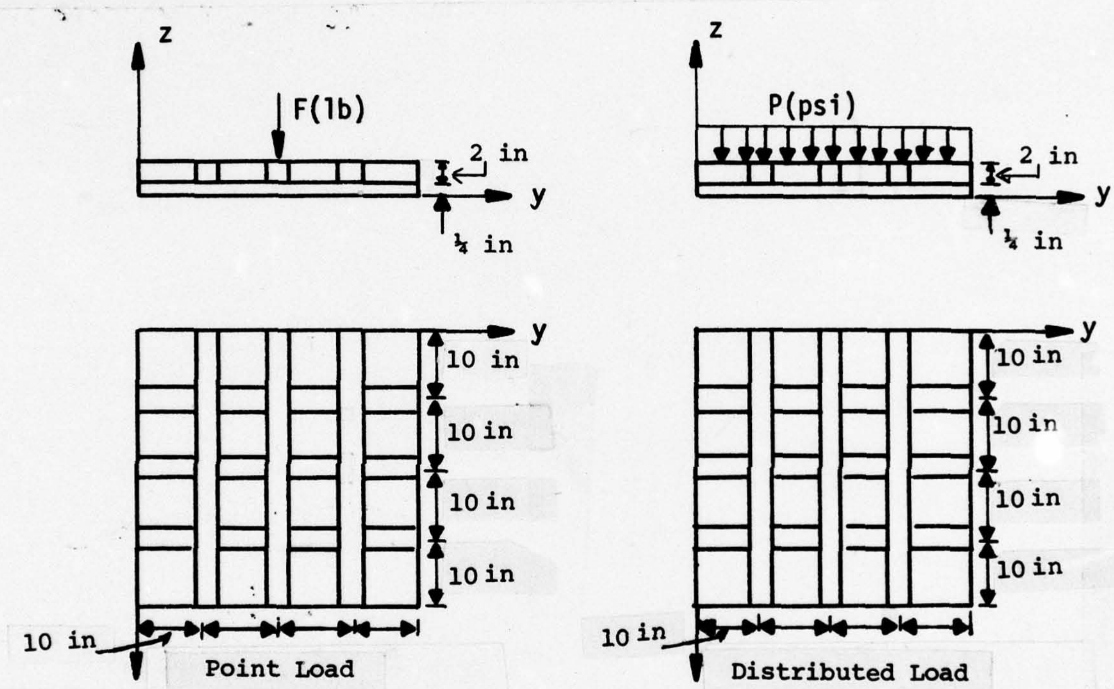


Figure 57. Time History of Plate Center - Uniform Load

5.3 Square Plate with Six Reinforcing Ribs

5.3.1 Load Functions

A simply supported square plate with six reinforcing ribs (Figure 58) is subjected to the same loads as problem 5.1.



Material: Steel

Members: 40 in x 40 in x ¼ in plate
2 in x 2 in x 40 in box beams
with wall thickness of ¼ in

Figure 58. Square Plate with Six Reinforcing Ribs

5.3.2 Finite Element Model

Again, only one-quarter of the plate is necessary for this analysis. A group of four thin plate elements and eight 3-D beam elements is used with the location of nodes and the elements shown in Figure 59.

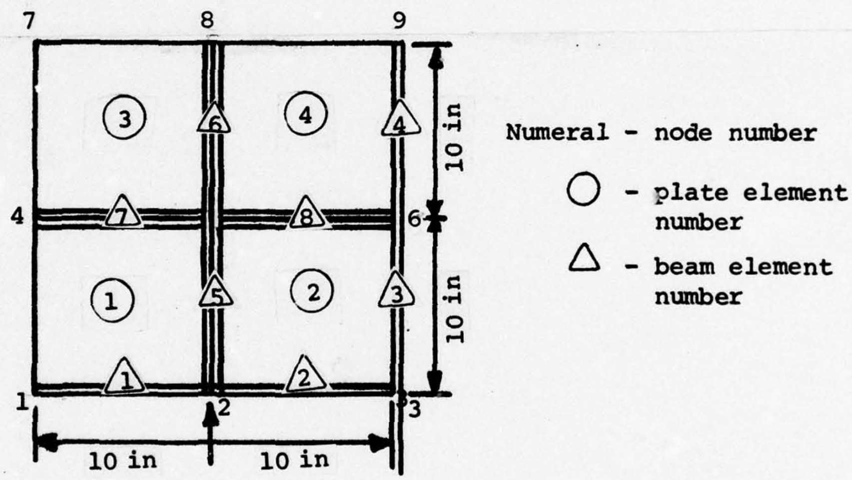


Figure 59. Element Assignment - Six-Ribbed Plate

5.3.3 Input Data - Case 1 - Static - Point Load

```
HEADER=*STATIC PLATE WITH REINFORCING RIBS
NUMNP=9,NELTYP=2,LL=1
IX(1)=0,1,1,0,1,1,
IX(2)=0,0,0,0,1,1,
IX(3)=0,0,0,1,1,1,
IX(4)=0,1,1,0,0,1,
IX(5)=0,0,0,0,0,1,
IX(6)=0,0,0,1,0,1,
IX(7)=1,1,1,0,0,1,
IX(8)=1,0,1,0,0,1,
IX(9)=1,0,1,1,0,1,
XYZT(1)=20.
XYZT(2)=20.,10.,
XYZT(3)=20.,20.,
XYZT(4)=10.,
XYZT(5)=10.,10.,
XYZT(6)=10.,20.,
XYZT(7)=,
XYZT(8)=,10.,
XYZT(9)=,20.,
NBEAM=8,BNEPC=2,BNMPC=1,
BMPC(1)=3.E7,.333,.0007346
BEPC(1)=.795,,,.0395,.383,.383
BEPC(2)=1.59,,,.079,.766,.766
BEAM(1)=1,2,4,1,1,,,,,,,,1
BEAM(3)=3,6,4,1,1,,,,,,,,3
BEAM(5)=2,5,7,1,2,,,,,,,,3
BEAM(7)=4,5,7,1,2,,,,,,,,1
BEAM(8)=5,6,7,1,2,
NPLATE=4,PNDM=1
PMPI(1)=.0007346,,,,3.375E7,1.125E7,,3.375E7,,1.125E7,
PELML=1.,
PLATE(1 4)=.25,-25.
IPLATE(1)=1,2,5,4,,1,1
IPLATE(3)=4,5,8,7,,1,1
IPLATE(4)=5,6,9,8,,1
IPLATE(4)=5,6,9,8,,1,
ELM(1)=1.,
'
```

5.3.4 Input Data - Case 2 - Dynamic - Point Load

```
HEADER=*DYNAMIC ANALYSIS OF A SIMPLY SUPPORTED PLATE W REIN RIBS
NUMNP=9,NELTYP=2,NF=10,NDYN=2,
IX(1)=0,1,1,0,1,1,        XYZT(1)=20.,
IX(2)=0,0,0,0,1,1,        XYZT(2)=20.,10.,
IX(3)=0,0,0,1,1,1,        XYZT(3)=20.,20.,
IX(4)=0,1,1,0,0,1,        XYZT(4)=10.,
IX(5)=0,0,0,0,0,1,        XYZT(5)=10.,10.,
IX(6)=0,0,0,1,0,1,        XYZT(6)=10.,20.,
IX(7)=1,1,1,0,0,1,        XYZT(7)=
IX(8)=1,0,1,0,0,1,        XYZT(8)=0.,10.,
IX(9)=1,0,1,1,0,1,        XYZT(9)=0.,20.,
NBEAM=8,BNEPC=2,BNMPC=1
BMPC(1)=3.E7,.333,.0007346
BEPC(1)=.795,,,.0395,.383,.383
BEPC(2)=1.59,,,.079,.766,.766
BEAM(1)=1,2,4,1,1,,,,,,,1
BEAM(3)=3,6,4,1,1,,,,,,,3
BEAM(5)=2,5,7,1,2,,,,,,,3
BEAM(7)=4,5,7,1,2,,,,,,,1
BEAM(8)=5,6,7,1,2
NPLATE=4,PNDM=1
PMPI(1)=.0007346,,,,3.375E7,1.125E7,,3.375E7,,1.125E7,
PLATE(1,3,4)=.25
IPLATE(1)=1,2,5,4,,1,1
IPLATE(3)=4,5,8,7,,1,1
IPLATE(4)=5,6,9,8,,1
IFPR=1,NFN=1,NT=1000,NOT=10,DT=.0001
NP(3,3)=1,,1
NLP(1)=4,-25.
T(1,1)=0.,T(1,2)=.002,T(1,3)=.01,T(1,4)=1.
F(1,1)=0.,F(1,2)=1.0,F(1,3)=0.,F(1,4)=0.
KKK=2
ICOMP(1 9)=1,2,3,4,5,6
KKKS=2
IS(2,1)=1,2,3,4,5,6,7,8,9,10,11,12
IS(2,2)=1,2,3,4,5,6,7,8,9,10,11,12
IS(2,3)=1,2,3,4,5,6,7,8,9,10,11,12
IS(2,4)=1,2,3,4,5,6,7,8,9,10,11,12
IS(2,5)=1,2,3,4,5,6,7,8,9,10,11,12
IS(2,6)=1,2,3,4,5,6,7,8,9,10,11,12
IS(2,7)=1,2,3,4,5,6,7,8,9,10,11,12
IS(2,8)=1,2,3,4,5,6,7,8,9,10,11,12
IS(6,1)=1,2,3,4,5,6
IS(6,2)=1,2,3,4,5,6
IS(6,3)=1,2,3,4,5,6
IS(6,4)=1,2,3,4,5,6
```

5.3.5 Input Data - Case 3 - Static Uniform Pressure

```
HEADER=*STATIC PLATE WITH REINFORCING RIBS
NUMNP=9,NELTYP=2,LL=1
IX(1)=0,1,1,0,1,1,
IX(2)=0,0,0,0,1,1,
IX(3)=0,0,0,1,1,1,
IX(4)=0,1,1,0,0,1,
IX(5)=0,0,0,0,0,1,
IX(6)=0,0,0,1,0,1,
IX(7)=1,1,1,0,0,1,
IX(8)=1,0,1,0,0,1,
IX(9)=1,0,1,1,0,1,
XYZT(1)=20.
XYZT(2)=20.,10.,
XYZT(3)=20.,20.,
XYZT(4)=10.,
XYZT(5)=10.,10.,
XYZT(6)=10.,20.,
XYZT(7)=,
XYZT(8)=,10.,
XYZT(9)=,20.,
NBEAM=4,BNEPC=1,BNMPC=1,
BMPC(1)=3.E7,.333,.0007346
BEPC(1)=.795,,,.0395,.383,.383
BEAM(1)=1,2,4,1,1,
BEAM(2)=2,3,4,1,1,
BEAM(3)=3,6,4,1,1,
BEAM(4)=6,9,4,1,1,
NPLATE=4,PNDM=1,
PMPI(1)=.0007346,,,,3.375E7.1.125E7,,3.375E7,,1.125E7
IPLATE(1)=1,2,5,4,,1
IPLATE(2)=2,3,6,5,,1
IPLATE(3)=4,5,8,7,,1
IPLATE(4)=5,6,9,8,,1
PELML=1.,
PLATE(1 4)=.25,-25.
ELM(1)=1.,
'
```

5.3.6 Input Data - Case 4 - Dynamic - Uniform Pressure

```
HEADER=*DYNAMIC ANALYSIS OF A SIMPLY SUPPORTED PLATE WITH REIN
NUMNP=9,NELTYP=2,NF=10,NDYN=2,
IX(1)=0,1,1,0,1,1,          XYZT(1)=20.,
IX(2)=0,0,0,0,1,1,          XYZT(2)=20.,10.,
IX(3)=0,0,0,1,1,1,          XYZT(3)=20.,20.,
IX(4)=0,1,1,0,0,1,          XYZT(4)=10.,
IX(5)=0,0,0,0,0,1,          XYZT(5)=10.,10.,
IX(6)=0,0,0,1,0,1,          XYZT(6)=10.,20.,
IX(7)=1,1,1,0,0,1,          XYZT(7)=
IX(8)=1,0,1,0,0,1,          XYZT(8)=0.,10.,
IX(9)=1,0,1,1,0,1,          XYZT(9)=0.,20.,
NBEAM=8,BNEPC=2,BNMPC=1,
BMPC(1)=3.E7,.3333,.0007346
BEPC(1)=.795,0.,0.,.0395,.383,.383
BEPC(2)=1.59,0.,0.,.079,.766,.766
BEAM(1)=1,2,4,1,1,,,,,,,,1
BEAM(3)=3,6,4,1,1,,,,,,,,3
BEAM(5)=2,5,7,1,2,,,,,,,,3
BEAM(7)=4,5,7,1,2,,,,,,,,1
BEAM(8)=5,6,7,1,2,
NPLATE=4,PNDM=1,
PMPI(1)=.0007346,,,,3.375E7,1.125E7,,3.375E7,,1.125E7,
PLATE(1,3,4)=.25,
IPLATE(1)=1,2,5,4,,1,1,
IPLATE(3)=4,5,8,7,,1,1,
IPLATE(4)=5,6,9,8,,1,
IFPR=1,NFN=1,NT=1000,NOT=10,DT=.0001,
NP(1,3)=1,,-62.5,
NP(2,3)=1,,-125.,
NP(3,3)=1,,-62.5,
NP(4,3)=1,,-125.,
NP(5,3)=1,,-250.,
NP(6,3)=1,,-125.,
NP(7,3)=1,,-62.5,
NP(8,3)=1,,-125.,
NP(9,3)=1,,-62.5,
NLP(1)=4,1.
T(1,1)=0.,T(1,2)=.002,T(1,3)=.01,T(1,4)=1.
F(1,1)=0.,F(1,2)=1.0,F(1,3)=0.,F(1,4)=0.
KKK=2,
ICOMP(1 9)=1,2,3,4,5,6
KKKS=2,
IS(2,1)=1,2,3,4,5,6,7,8,9,10,11,12,
IS(2,2)=1,2,3,4,5,6,7,8,9,10,11,12,
IS(2,3)=1,2,3,4,5,6,7,8,9,10,11,12,
IS(2,4)=1,2,3,4,5,6,7,8,9,10,11,12,
IS(2,5)=1,2,3,4,5,6,7,8,9,10,11,12,
IS(2,6)=1,2,3,4,5,6,7,8,9,10,11,12,
IS(2,7)=1,2,3,4,5,6,7,8,9,10,11,12,
IS(2,8)=1,2,3,4,5,6,7,8,9,10,11,12,
IS(6,1)=1,2,3,4,5,6
IS(6,2)=1,2,3,4,5,6
IS(6,3)=1,2,3,4,5,6
IS(6,4)=1,2,3,4,5,6
```

5.3.7 Results

Case 1 - Static - Concentrated Load

Maximum Deflection (at center)	=	-0.1454×10^{-2} in
Maximum Bending Moment (at center in beam element)	=	1.637×10^{2} lb-in

Case 3 - Static - Distributed Load

Maximum Deflection (at center)	=	-0.19624 in
Maximum Bending Moment (at node 2, or 5 in beam element)	=	1.585×10^{4} lb-in

The displacement responses at the center node for the two dynamic forcing functions are shown in Figures 60 and 61.

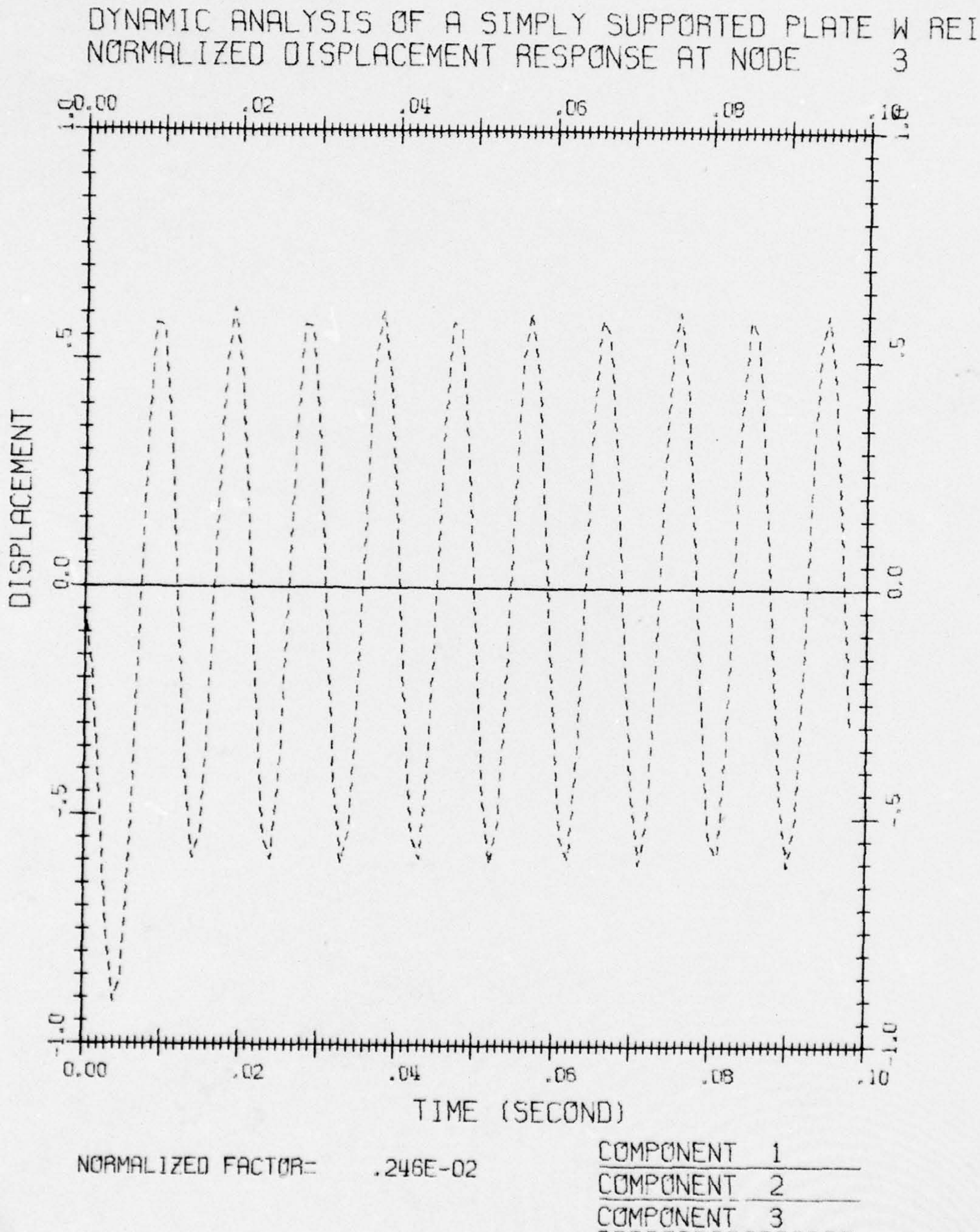


Figure 60. Nodal Displacement - Plate Center - Point Load

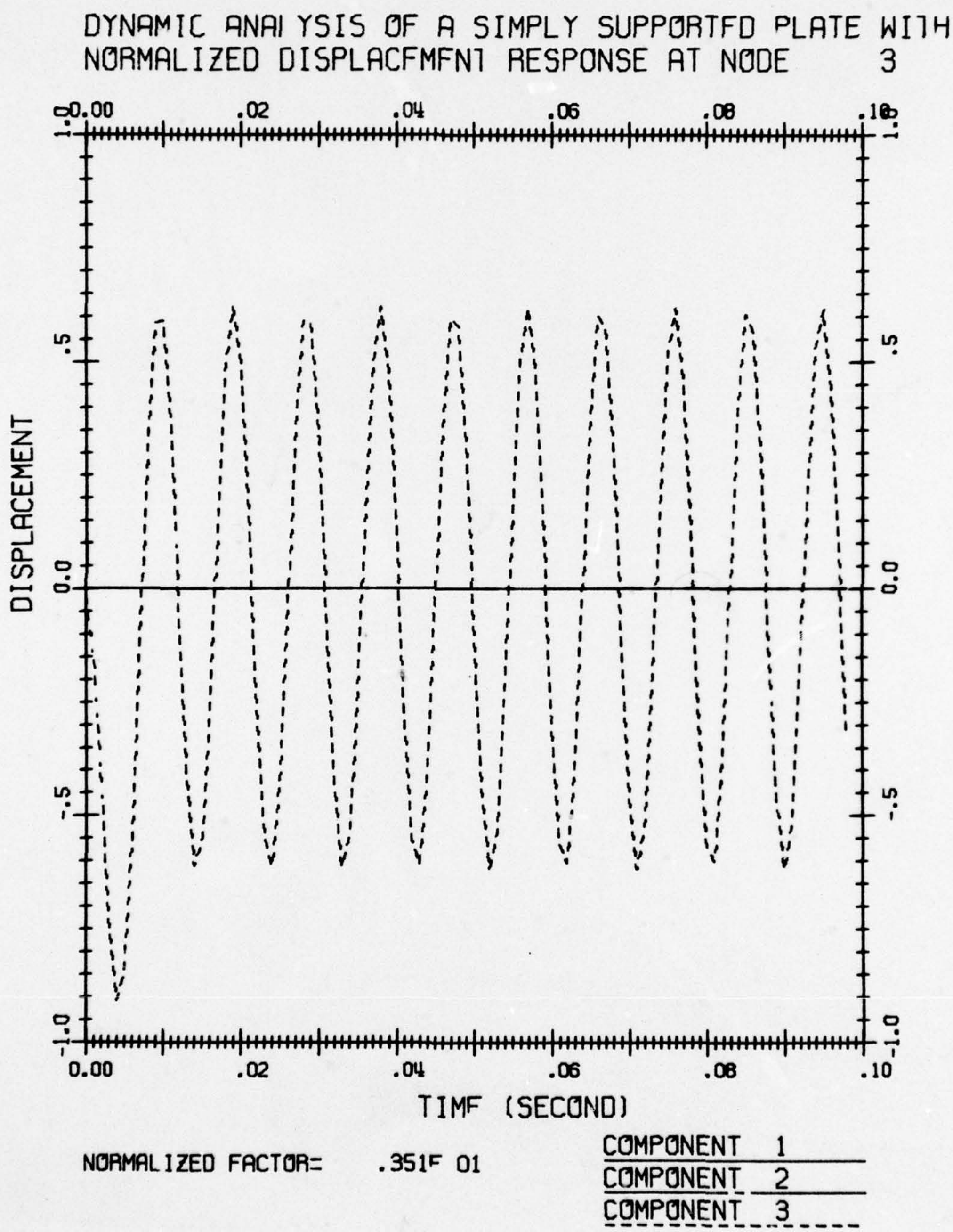


Figure 61. Nodal Displacement Plate Center - Uniform Load

5.4 Thick Rectangular Plate Analyses Utilizing Thick Shell Elements

5.4.1 Load Functions

A simply supported rectangular plate is subjected to the following loads:

Case 1. Static point load at the center of the top face, and

Case 2. Dynamic point load at the center of the top face with the time history shown in Figure 62.

Case 3. Dynamic uniform pressure on the top face with the time history shown in Figure 62.

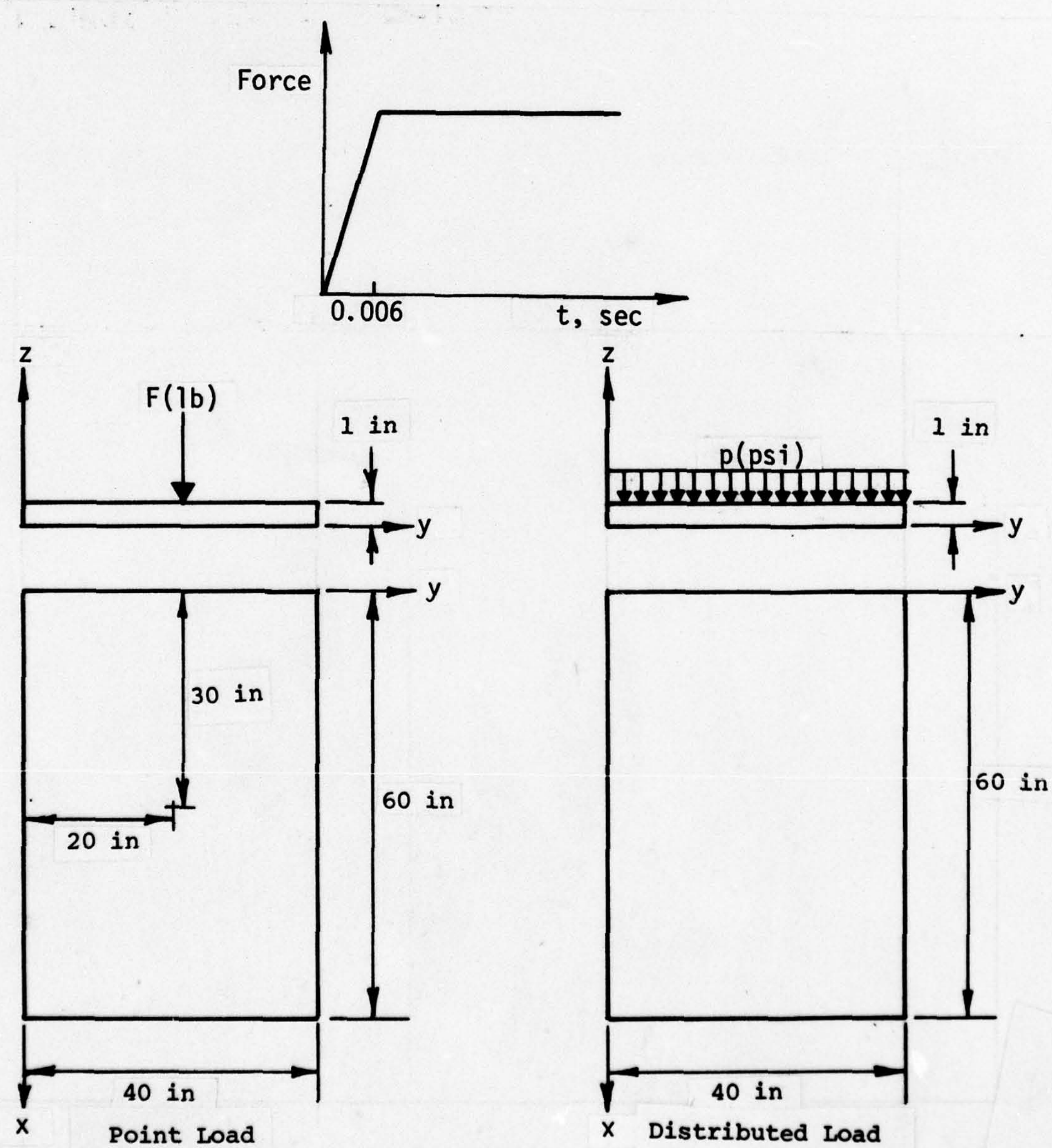


Figure 62. Thick Rectangular Plate - Static and Dynamic Loading

5.4.2 Finite Element Model

Due to symmetry one-quarter of the plate is adequate for this analysis. A group of four thick shell elements is used with the location of nodes and elements shown in Figure 63.

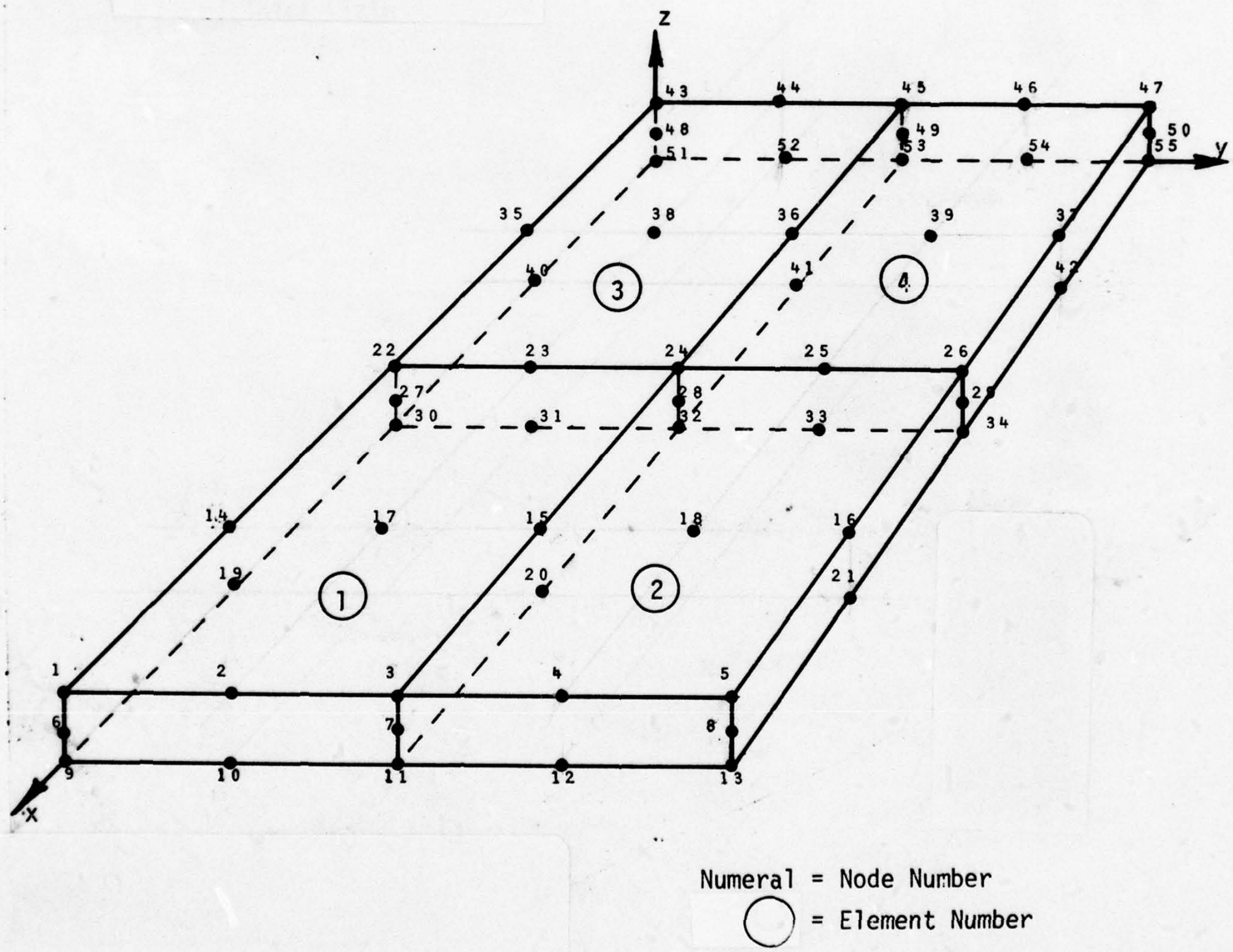


Figure 63. Element Assignment - Thick Plate

5.4.3 Input Data - Case 1 - Static - Point Load

```
HEADER=*STATIC ANALYSIS OF SIMPLY SUPPORTED THICK PLATE (21.NODE ELEMENT)        *
NUMNP=55,NELTYP=1,LL=1,
IX(1 4,6,7,10 12)=                                                    1,0,0,1,1,1,
IX(5,8,13)=                                                           1,1,0,1,1,1,
IX(9)=                                                                1,0,1,1,1,1,
IX(14,15,17,18,20,22,25,27,28,31,33,35,36,38,39,41,43 46,48,49)=      0,0,0,1,1,1,
IX(16,21,26,29,34,37,42,47,50)=                                       0,1,0,1,1,1,
IX(19,30,40,51,52,54)=                                                0,0,1,1,1,1,
IX(55)=                                                               0,1,1,1,1,1,
XYZT(1)=30.,,1.
XYZT(4)=30.,15.,1.,
XYZT(5)=30.,20.,1.,
XYZT(6)=30.,,,.5
XYZT(7)=30.,10.,,.5
XYZT(8)=30.,20.,,.5
XYZT(9)=30.,
XYZT(10)=30.,5.,
XYZT(13)=30.,20.,
XYZT(14)=22.5,,1.
XYZT(15)=22.5,10.,1.,
XYZT(16)=22.5,20.,1.,
XYZT(17)=22.5,5.,,.5,
XYZT(18)=22.5,15.,,.5,
XYZT(19)=22.5,
XYZT(20)=22.5,10.,
XYZT(21)=22.5,20.,
XYZT(22)=15.,,1.,
XYZT(25)=15.,15.,1.,
XYZT(26)=15.,20.,1.,
XYZT(27)=15.,,,.5,
XYZT(28)=15.,10.,,.5
XYZT(29)=15.,20.,,.5
XYZT(30)=15.
XYZT(31)=15.,5.
XYZT(33)=15.,15.,
XYZT(34)=15.,20.,
```

Input Data - Case 1 - Static - Point Load (Concluded)

```
XYZT(35)=7.5,,1.,
XYZT(36)=7.5,10.,1.,
XYZT(37)=7.5,20.,1.,
XYZT(38)=7.5,5.,.5,
XYZT(39)=7.5,15.,.5
XYZT(40)=7.5,
XYZT(41)=7.5,10.,
XYZT(42)=7.5,20.,
XYZT(43)=,,1.,
XYZT(46)=.15.,1.,
XYZT(47)=,20.,1.,
XYZT(48)=,,.5
XYZT(49)=,10.,.5,
XYZT(50)=,20.,.5,
XYZT(51)=
XYZT(52)=,5.,
XYZT(54)=,15.,
XYZT(55)=,20.,
NSOL21=4,NUMMAT=1,MAXTP=1,MAXNOD=21,NOPSET=1,INIRS=4,INTT=3
NTP(1)=1
MASSDN(1)=.3E-3
MATEV(1,1)=,3.E4,3.E4,3.E4,.25,.25,.25
MATGA(1,1)=1.2E4,1.2E4,1.2E4
SSORLS(1)=1.2,3,4,6.7,8
SHELL1(1 4)=,,1,,1
S1TO8(1)=24,22,1,3,32,30,9,11,
S9TO16(1)=23,14,2,15,31,19,10,20
S17TO21(1)=28,27,6,7,17
S1TO8(2)=26,24,3,5,34,32,11,13,
S9TO16(2)=25,15,4,16,33,20,12,21
S17TO21(2)=29,28,7,8,18
S1TO8(3)=45,43,22,24,53,51,30,32
S9TO16(3)=44,35,23,36,52,40,31,41
S17TO21(3)=49,48,27,28,38
S1TO8(4)=47,45,24,26,55,53,32,34
S9TO16(4)=46,36,25,37,54,41,33,42,
S17TO21(4)=50,49,28,29,39
CLMD(5,1)=,,-10.,
'
```

5.4.4 Input Data - Case 2 - Dynamic - Point Load

```
HEADER=*DYNAMIC ANALYSIS OF SIMPLY SUPPORTED THICK PLATE                  *
NUMNP=55,NELTYP=1,NF=24,NDYN=2,
IX(1 4,6,7,10 12)=1,0,0,1,1,1,
IX(5,8,13)=1,1,0,1,1,1,
IX(9)=1,0,1,1,1,1,
IX(14,15,17,18,20,22,25,27,28,31,33,35,36,38,39,41,43,46,48,49)=0,0,0,1,1,1
IX(16,21,26,29,34,37,42,47,50)=0,1,0,1,1,1
IX(19,30,40,51 54)=0,0,1,1,1,1,
IX(55)=0,1,1,1,1,1,
XYZT(1)=30.,,1.
XYZT(4)=30.,15.,1.,
XYZT(5)=30.,20.,1.,
XYZT(6)=30.,,.5
XYZT(7)=30.,10.,.5
XYZT(8)=30.,20.,.5
XYZT(9)=30.,
XYZT(10)=30.,5.,
XYZT(13)=30.,20.,
XYZT(14)=22.5,,1.
XYZT(15)=22.5,10.,1.,
XYZT(16)=22.5,20.,1.,
XYZT(17)=22.5,5.,.5,
XYZT(18)=22.5,15.,.5,
XYZT(19)=22.5,
XYZT(20)=22.5,10.,
XYZT(21)=22.5,20.,
XYZT(22)=15.,,1.,
XYZT(25)=15.,15.,1.,
XYZT(26)=15.,20.,1.,
XYZT(27)=15.,,.5,
XYZT(28)=15.,10.,.5
XYZT(29)=15.,20.,.5
XYZT(30)=15.
XYZT(31)=15.,5.
XYZT(33)=15.,15.,
XYZT(34)=15.,20.,
```

Input Data - Case 2 - Dynamic - Point Load (Continued)

```
XYZT(35)=7.5,,1.,
XYZT(36)=7.5,10.,1.,
XYZT(37)=7.5,20.,1.,
XYZT(38)=7.5,5.,.5,
XYZT(39)=7.5,15.,.5
XYZT(40)=7.5,
XYZT(41)=7.5,10.,
XYZT(42)=7.5,20.,
XYZT(43)=,,1.,
XYZT(46)=,15.,1.,
XYZT(47)=,20.,1.,
XYZT(48)=,,.5
XYZT(49)=,10.,.5,
XYZT(50)=,20.,.5,
XYZT(51)=
XYZT(52)=,5.,
XYZT(54)=,15.,
XYZT(55)=,20.,
NSOL21=4,NUMMAT=1,MAXTP=1,MAXNOD=21,NOPSET=1,INTRS=4,INTT=3,
NTP(1)=1,MASSDN(1)=.3E-3,
MATEV(1,1)=,3.E4,3.E4,3.E4,.25,.25,.25
MATGA(1,1)=1.2E4,1.2E4,1.2E4
SSORLS(1)=1,2,3,4,6,7,8
SHELL1(1)=,,1,,1
S1TO8(1)=24,22,1,3,32,30,9,11,
S9TO16(1)=23,14,2,15,31,19,10,20,
S17TO21(1)=28,27,6,7,17
SHELL1(2)=,,1,,1
SHELL2(2)=,,,1
S1TO8(2)=26,24,3,5,34,32,11,13,
S9TO16(2)=25,15,4,16,33,20,12,21
S17TO21(2)=29,28,7,8,18
SHELL1(3)=,,1,,1
SHELL2(3)=,,,1
S1TO8(3)=45,43,22,24,53,51,30,32,
```

Input Data - Case 2 - Dynamic - Point Load (Concluded)

```
S9TO16(3)=44,35,23,36,52,40,31,41
S17TO21(3)=49,48,27,28,38
SHELL1(4)=,,1,,1
SHELL2(4)=,,,1
S1TO8(4)=47,45,24,26,55,53,32,34,
S9TO16(4)=46,36,25,37,54,41,33,42
S17TO21(4)=50,49,28,29,39
NFN=1,NT=1000,NOT=10,DT=.0005
NP(5,3)=1,,1.
NLP(1)=3,-1.
T(1,1)=0.,T(1,2)=.006,T(1,3)=5.
F(1,1)=0.,F(1,2)=1.0,F(1,3)=1.
KKK=2
ICOMP(7,8,28,29)=3
KKKS=2
IS(8,2)=31,32,33,34,35,36,37,38,39,40,41,42
'
```

5.4.5 Input Data - Case 3 - Dynamic - Uniform Pressure

```
HEADER=*DYNAMIC ANALYSIS OF SIMPLY SUPPORTED THICK PLATE                    *
NUMNP=55,NELTYP=1,NF=24,NDYN=2,
IX(1 4,6,7,10 12)=1,0,0,1,1,1,
IX(5,8,13)=1,1,0,1,1,1,
IX(9)=1,0,1,1,1,1,
IX(14,15,17,18,20,22,25,27,28,31,33,35,36,38,39,41,43,46,48,49)=0,0,0,1,1,1
IX(16,21,26,29,34,37,42,47,50)=0,1,0,1,1,1
IX(19,30,40,51 54)=0,0,1,1,1,1,
IX(55)=0,1,1,1,1,1,
XYZT(1)=30.,,1.
XYZT(4)=30.,15.,1.,
XYZT(5)=30.,20.,1.,
XYZT(6)=30.,,,.5
XYZT(7)=30.,10.,,.5
XYZT(8)=30.,20.,,.5
XYZT(9)=30.,
XYZT(10)=30.,5.,
XYZT(13)=30.,20..
XYZT(14)=22.5,,1.
XYZT(15)=22.5,10.,1.,
XYZT(16)=22.5,20.,1.,
XYZT(17)=22.5,5.,,.5,
XYZT(18)=22.5,15.,,.5,
XYZT(19)=22.5,
XYZT(20)=22.5,10.,
XYZT(21)=22.5,20.,
XYZT(22)=15.,,1.,
XYZT(25)=15.,15.,1.,
XYZT(26)=15.,20.,1.,
XYZT(27)=15.,,,.5,
XYZT(28)=15.,10.,,.5
XYZT(29)=15.,20.,,.5
XYZT(30)=15.
XYZT(31)=15.,5.
XYZT(33)=15.,15.,
XYZT(34)=15.,20.,
```

Input Data - Case 3 - Dynamic - Uniform Pressure (Continued)

```
XYZT(35)=7.5,,1.,
XYZT(36)=7.5,10.,1.,
XYZT(37)=7.5,20.,1.,
XYZT(38)=7.5,5.,.5,
XYZT(39)=7.5,15.,.5
XYZT(40)=7.5,
XYZT(41)=7.5,10.,
XYZT(42)=7.5,20.,
XYZT(43)=,,1.,
XYZT(46)=,15.,1.,
XYZT(47)=,20.,1.,
XYZT(48)=,,.5
XYZT(49)=,10.,.5,
XYZT(50)=,20.,.5,
XYZT(51)=
XYZT(52)=.5.,
XYZT(54)=,15.,
XYZT(55)=,20.,
NSOL21=4,NUMMAT=1,MAXTP=1,MAXNOD=21,NOPSET=1,INTRS=4,INTT=3,
NTP(1)=1,MASSDN(1)=.3E-3,
MATEV(1,1)=,3.E4.3.E4,3.E4,.25,.25,.25
MATGA(1,1)=1.2E4,1.2E4,1.2E4
SSORLS(1)=1,2,3,4,6,7,8
SHELL1(1)=,,1,,1
S1TO8(1)=24,22,1,3,32,30,9,11,
S9TO16(1)=23,14,2,15,31,19,10,20,
S17TO21(1)=28,27,6,7,17
SHELL1(2)=,,1,,1
SHELL2(2)=,,,1
S1TO8(2)=26,24,3,5,34,32,11,13,
S9TO16(2)=25,15,4,16,33,20,12,21
S17TO21(2)=29,28,7,8,18
SHELL1(3)=,,1,,1
SHELL2(3)=,,,1
S1TO8(3)=45,43,22,24,53,51,30,32,
S9TO16(3)=44,35,23,36,52,40,31,41
S17TO21(3)=49,48,27,28,38
```

Input Data - Case 3 - Dynamic - Uniform Pressure (Concluded)

```
SHELL1(4)=,,1,,1
SHELL2(4)=,,,1
S1TO8(4)=47,45,24,26,55,53,32,34,
S9TO16(4)=46,36,25,37,54,41,33,42
S17TO21(4)=50,49,28,29,39
NFN=1,NT=1000,NOT=10,DT=.0005
NP(1,3)=1,,9.375
NP(2,3)=1,,18.75
NP(3,3)=1,,18.75
NP(4,3)=1,,18.75
NP(5,3)=1,,9.375
NP(14,3)=1,,37.5
NP(15,3)=1,,75.
NP(16,3)=1,,37.5
NP(22,3)=1,,18.75
NP(23,3)=1,,37.5
NP(24,3)=1,,37.5
NP(25,3)=1,,37.5
NP(26,3)=1,,18.75
NP(35,3)=1,,37.5
NP(36,3)=1,,75.
NP(37,3)=1,,37.5
NP(43,3)=1,,9.375
NP(44,3)=1,,18.75
NP(45,3)=1,,18.75
NP(46,3)=1,,18.75
NP(47,3)=1,,9.375
NLP(1)=3,-1.
T(1,1)=0.,T(1,2)=.006,T(1,3)=5.
F(1,1)=0.,F(1,2)=1.0,F(1,3)=1.
KKK=2
ICOMP(7,8,28,29)=3
KKKS=2
IS(8,2)=31,32,33,34,35,36,37,38,39,40,41,42
```

5.4.6 Results

Case 1 - Static - Concentrated Load

Maximum Deflection:
- 0.031335 in (SAP IV)
- 0.036768 in (Thin Plate Theory)

The displacement response curves at the centroid for the two dynamic forcing functions are shown in Figures 64 and 65.

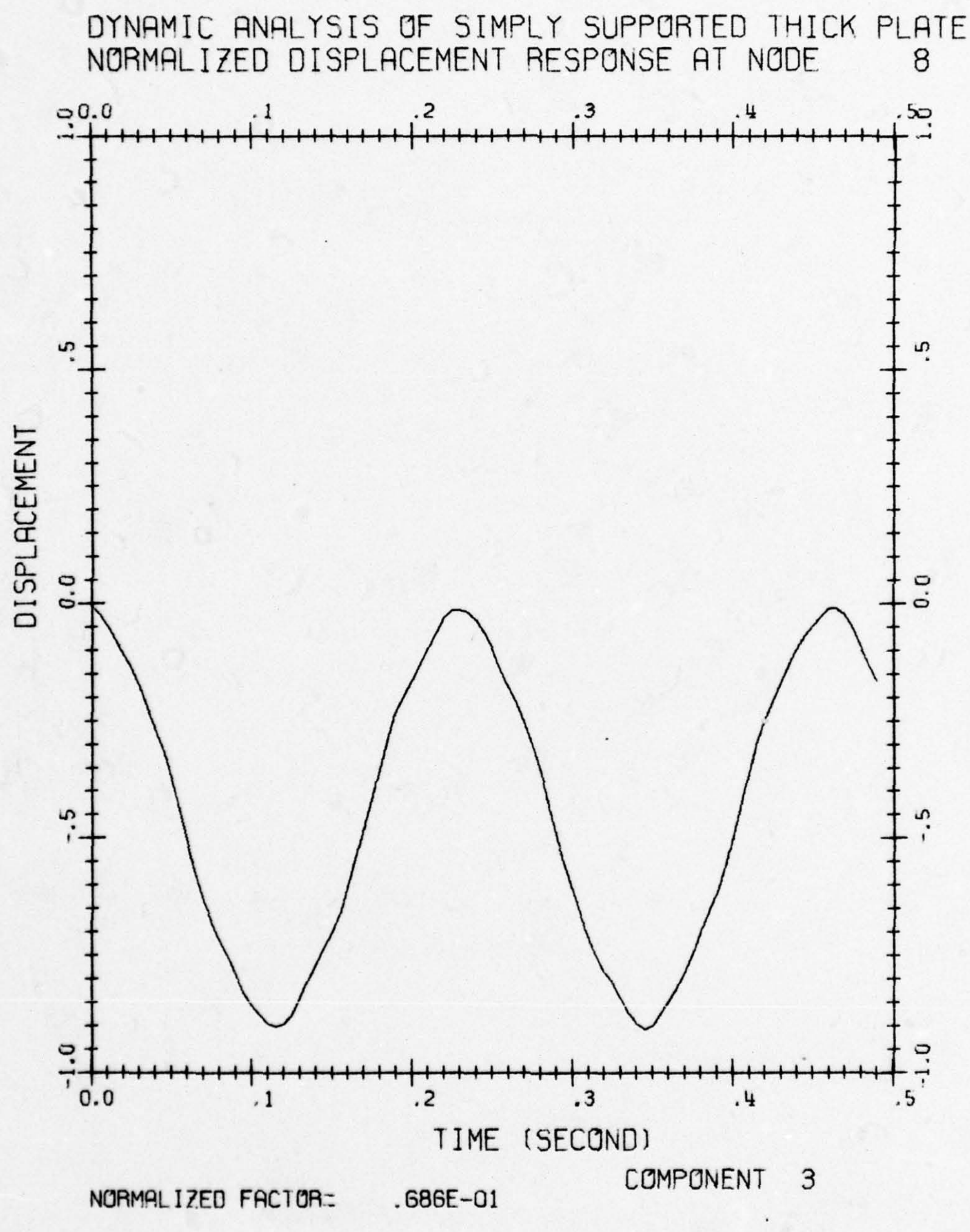


Figure 64. Nodal Response at Plate Center - Point Load

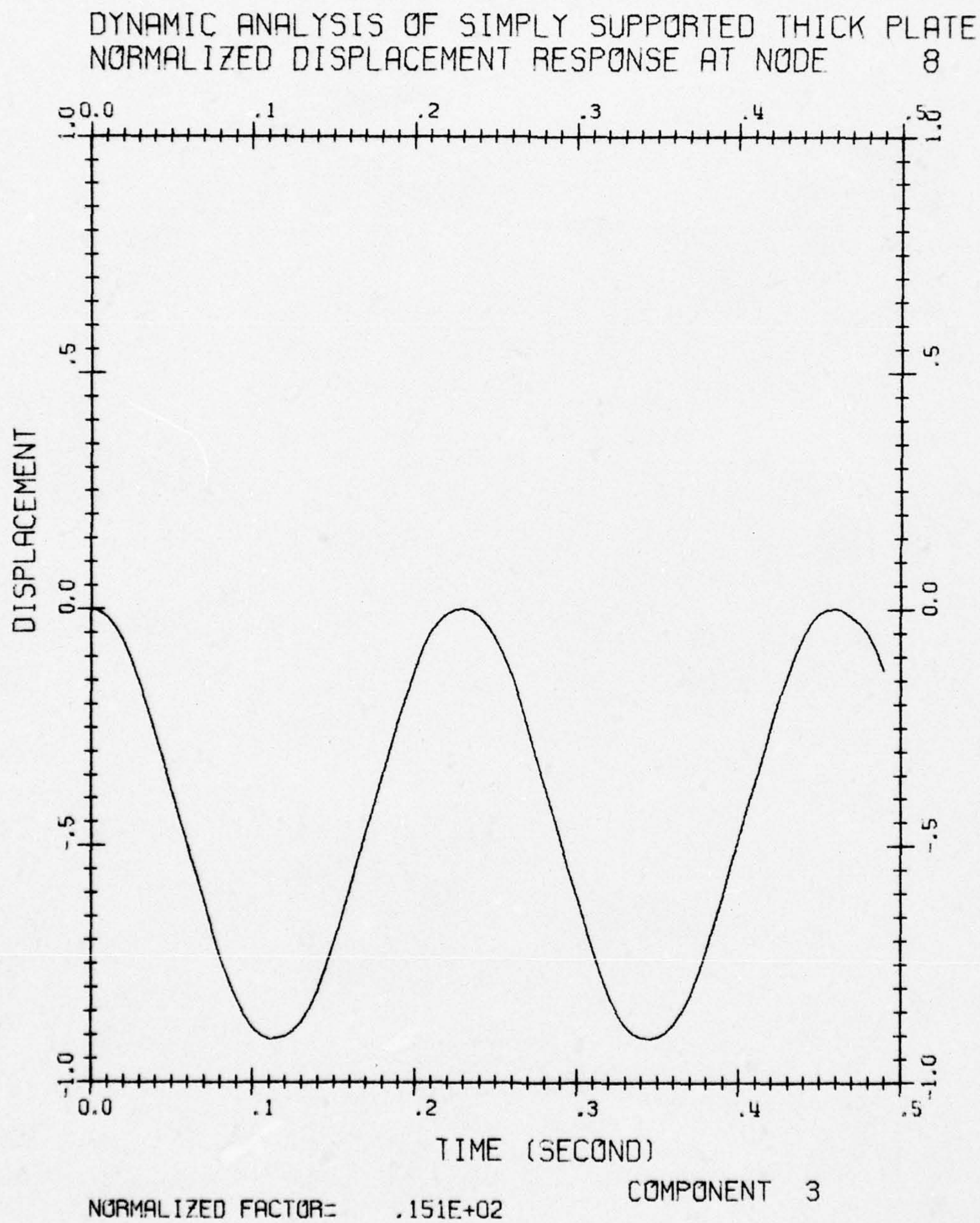


Figure 65. Nodal Response at Plate Center - Uniform Load

6. AIRCRAFT SHELTER COMPONENTS

6.1 Static and Dynamic Analyses of 24-foot Radius Arch

6.1.1 Introduction

A 24-foot radius arch was chosen to represent a segment of a typical aircraft shelter and was composed of reinforced concrete that was equivalent to the reinforced concrete covered doubly corrugated steel panel of a hardened aircraft shelter. The cross-section of the shelter that was modeled is the same as that shown in problem 4.5.

6.1.2 Six, 21-node thick shell elements were used to model the arch. A typical thick shell element with the location of the nodes and the natural coordinate system is shown in Figure 66.

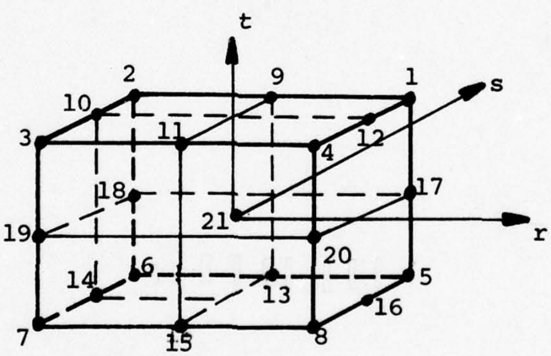


Figure 66. 21-Node Element

The assignment of nodes and elements for the model is shown in Figures 67 and 68. The node point coordinates were input in terms of cylindrical coordinates and converted to the x, y, z coordinate system shown in the figure by SAP IV, which uses the following relationships:

$$x = R(\sin\theta),\ y = y,\ z = R\ (\cos\theta)$$

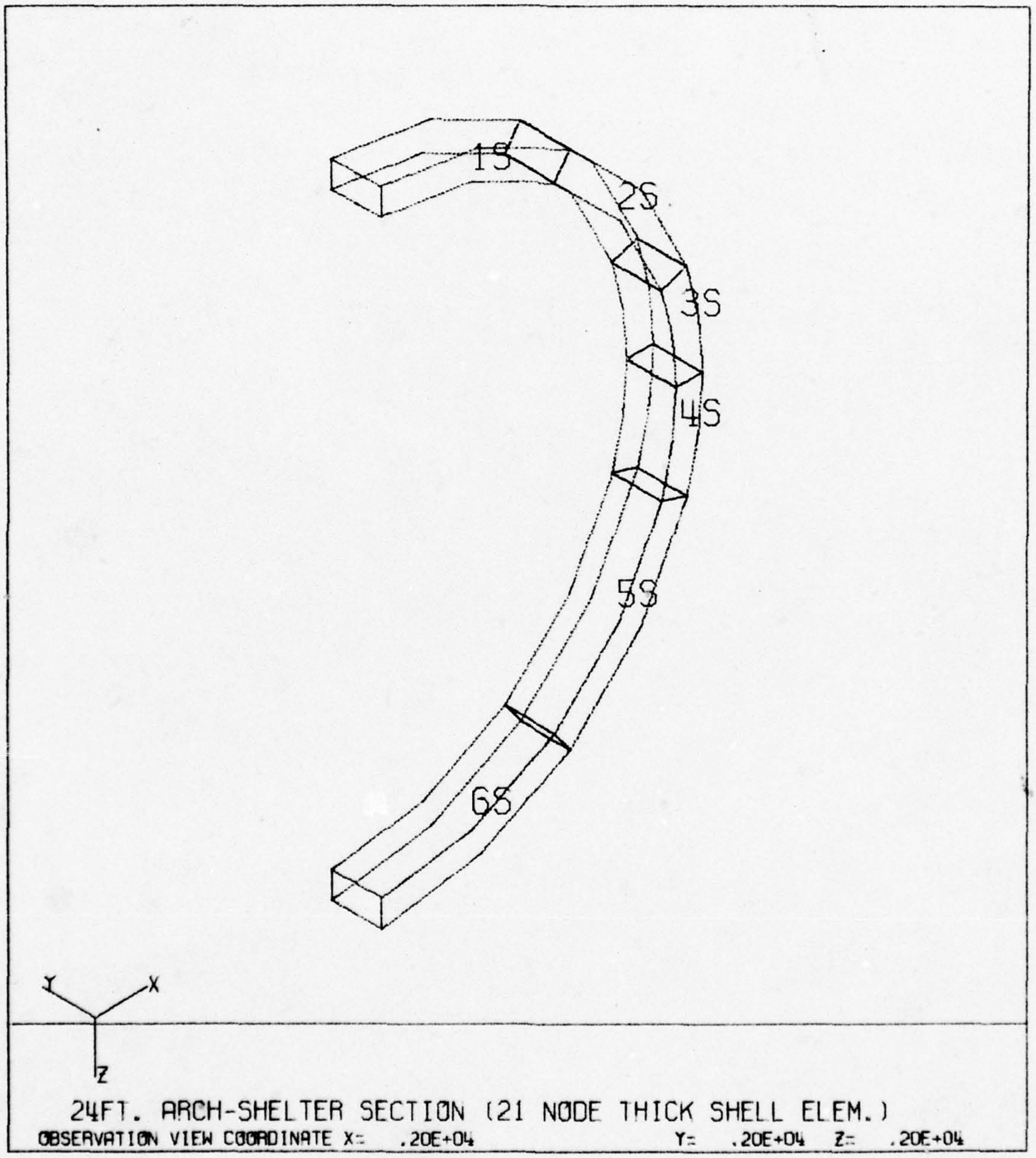


Figure 67. Element Assignment - Arch

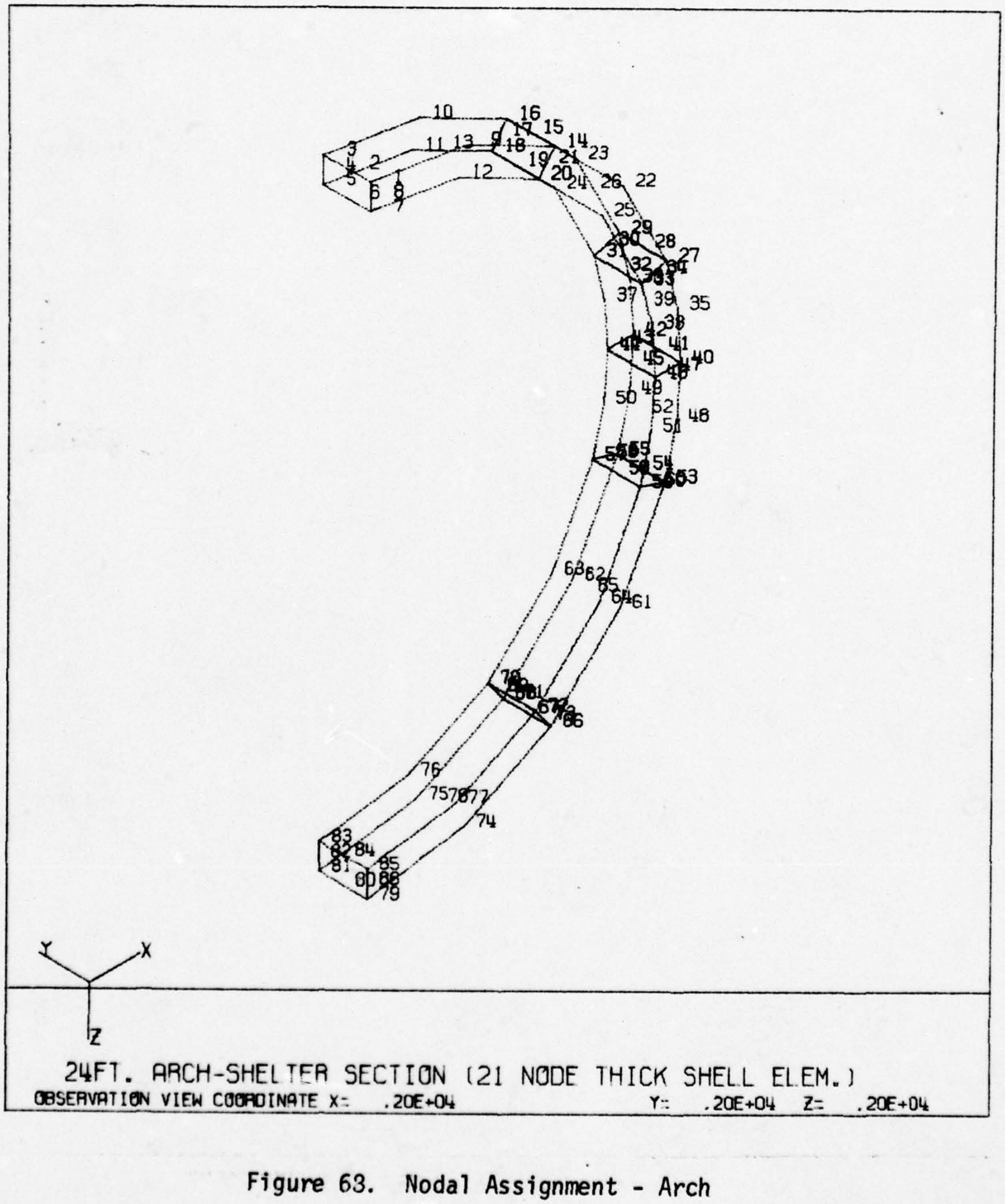


Figure 63. Nodal Assignment - Arch

For the arch, an equivalent thickness was chosen to match the flexural rigidity in the circumferential direction of a hardened aircraft shelter. Using the relation $I = (b/12)\, h^3$, with an I of 36,189 in^4 and a width of 24 in results in an

$$h \text{ of } \sqrt[3]{\frac{12(36189 \text{ in}^4)}{24 \text{ in}}} = 26.25 \text{ in}$$

6.1.3 Static Analysis of 24-foot Radius Arch

For the static analysis the arch was loaded with a uniform pressure of 36.7 psi. This pressure approximated the peak free-field overpressure of the Mixed Company event at a range of 600 feet.

6.1.4 Input Data - 24-Foot Radius Arch - Static (continued)

```
HEADER=*24FT. ARCH-SHELTER SECTION (21 NO+E THICK SHELL ELEM.)                    *
NUMNP=86,NELTYP=1,LL=1
CT(1 86)=C
IX(1,79,8,7,85,2,6,80,84,3,81,4,82,5,83,86)=                               1,1,1,1,1,1,
IX(9,14,22,27,35,40,48,53,61,66,74,21,34, 7,60,73,12,20,25,33,38)= 0,0,0,1,1,1,
IX(46,51,59,64,72,77,13,15,19,26,28,32,39,41,45,52,54,58,65,67)=   0,0,0,1,1,1,
IX(71,78,10,16,23,29,36,42,49,55,62,68,75,17,30,43,56,69,11,18)=   0,0,0,1,1,1,
IX(24,31,37,44,50,57,63,70,76)=                                    0,0,0,1,1,1,
XYZT(1)=314.25,0.,180.
XYZT(9)=314.25,0.,162.
XYZT(14)=314.25,0.,144.
XYZT(22)=314.25,0.,126.,
XYZT(27)=314.25,0.,108.,
XYZT(35)=314.25,0.,99.,
XYZT(40)=314.25,0.,90.,
XYZT(48)=314.25,0.,81.,
XYZT(53)=314.25,0.,72.,
XYZT(61)=314.25,0.,54.,
XYZT(66)=314.25,0.,36.,
XYZT(74)=314.25,0.,18.,
XYZT(79)=314.25,0.,0.,
XYZT(8)=301.125,0.,180.,
XYZT(21)=301.125,0.,144.,
XYZT(34)=301.125,0.,108.,
XYZT(47)=301.125,0.,90.
XYZT(60)=301.125,0.,72.
XYZT(73)=301.125,0.,36.
XYZT(7)=288.,0.,180.
XYZT(12)=288.,0.,162.
XYZT(20)=288.,0.,144.
XYZT(25)=288.,0.,126.
XYZT(33)=288.,0.,108.
XYZT(38)=288.,0.,99.,
XYZT(46)=288.,0.,90.,
XYZT(51)=288.,0.,81.,
```

Input Data - 24-Foot Radius Arch - Static (Continued)

```
XYZT(59)=288.,0.,72.,
XYZT(64)=288.,0.,54.,
XYZT(72)=288.,0.,36.,
XYZT(77)=288.,0.,18.,
XYZT(85)=288.,0.,0.,
XYZT(2)=314.25,24.,180.,
XYZT(6)=288.,24.,180.,
XYZT(13)=301.125,24.,162.,
XYZT(15)=314.25,24.,144.
XYZT(19)=288.,24.,144.
XYZT(26)=301.125,24.,126.
XYZT(28)=314.25,24.,108.
XYZT(32)=288.,24.,108.
XYZT(39)=301.125,24.,99.
XYZT(41)=314.25,24.,90.
XYZT(45)=288.,24.,90.
XYZT(52)=301.125,24.,81.,
XYZT(54)=314.25,24.,72.
XYZT(58)=288.,24.,72.,
XYZT(65)=301.125,24.,54.,
XYZT(67)=314.25,24.,36.
XYZT(71)=288.,24.,36.
XYZT(78)=301.125,24.,18.
XYZT(80)=314.25,24.,0.,
XYZT(84)=288.,24.,0.,
XYZT(3)=314.25,48.,180.,
XYZT(10)=314.25,48.,162.,
XYZT(16)=314.25,48.,144.,
XYZT(23)=314.25,48.,126.,
XYZT(29)=314.25,48.,108.,
XYZT(36)=314.25,48.,99.,
XYZT(42)=314.25,48.,90.,
XYZT(49)=314.25,48.,81.,
XYZT(55)=314.25,48.,72.,
XYZT(62)=314.25,48.,54.,
XYZT(68)=314.25,48.,36.,
```

Input Data - 24-Foot Radius Arch - Static (Continued)

```
XYZT(75)=314.25,48.,18.,
XYZT(81)=314.25,48.,0.,
XYZT(4)=301.125,48.,180.,
XYZT(17)=301.125,48.,144.,
XYZT(30)=301.125,48.,108.,
XYZT(43)=301.125,48.,90.,
XYZT(56)=301.125,48.,72.,
XYZT(69)=301.125,48.,36.,
XYZT(82)=301.125,48.,0.,
XYZT(5)=288.,48.,180.,
XYZT(11)=288.,48.,162.,
XYZT(18)=288.,48.,144.,
XYZT(24)=288.,48.,126.,
XYZT(31)=288.,48.,108.,
XYZT(37)=288.,48.,99.,
XYZT(44)=288.,48.,90.,
XYZT(50)=288.,48.,81.,
XYZT(57)=288.,48.,72.,
XYZT(63)=288.,48.,54.,
XYZT(70)=288.,48.,36.,
XYZT(76)=288.,48.,18.,
XYZT(83)=288.,48.,0.,
XYZT(86)=301.125,
NSOL21=6,NUMMAT=1,MAXTP=1,NDLS=1,MAXNOD=21,NOPSET=1,INTRS=4,INTT=3
NTP(1)=1
MASSDN(1)=2.1716E-4
MATEV(1,1)=,3.644E6,3.644E6,3.644E6,.17,.17,.17
MATGA(1,1)=1.5573E6,1.5573E6,1.5573E6
SDSLDI(1)=5,1
SDSLDF(1)=36.7
SSORLS(1)=1,2,3,4,5,6,8
SELCMP=1.,
SHELL1(1)=,,1,,1
SHELL1(2 6)=,,1,,1
SHELL2(1 6)=,,,,1
S1TO8(1)=14,1,3,16,20,7,5,18
```

Input Data - 24-Foot Radius Arch - Static (Concluded)

```
S9T016(1)=9,2,10,15,12,6,11,19
S17T021(1)=21,8,4,17,13
S1T08(2)=27,14,16,29,33,20,18,31
S9T016(2)=22,15,23,28,25,19,24,32
S17T021(2)=34,21,17,30,26
S1T08(3)=40,27,29,42,46,33,31,44
S9T016(3)=35,28,36,41,38,32,37,45
S17T021(3)=47,34,30,43,39
S1T08(4)=53,40,42,55,59,46,44,57,
S9T016(4)=48,41,49,54,51,45,50,58
S17T021(4)=60,47,43,56,52
S1T08(5)=66,53,55,68,72,59,57,70
S9T016(5)=61,54,62,67,64,58,63,71
S17T021(5)=73,60,56,69,65
S1T08(6)=79,66,68,81,85,72,70,83
S9T016(6)=74,67,75,80,77,71,76,84
S17T021(6)=86,73,69,82,78
FLM(1)=1.
'
8.
X(2000.)A()
Y(2000.)A()
Z(2000.)A()
X(2000.)Y(2000.)A()
X(2000.)Z(2000.)A()
Y(2000.)Z(2000.)A()
X(2000.)Z(2000.)Y(2000.)A()
X(2000.)Y(2000.)Z(2000.)AN()
X(2000.)Y(2000.)Z(2000.)AE()
X(2000.)Y(2000.)Z(2000.)ANE()
'
'
```

6.1.5 Results

As an example of the results for the static load, consider the vertical and lateral displacements of nodes 28 and 54 which are symmetrical about the crown.

NODE	VERT. DISPL.	LAT. DISPL.
28	-0.0644 in	+0.0113 in
54	-0.0644 in	-0.0113 in

6.1.6 Analysis of a 24-Foot Radius Arch Under a Dynamic Load

For the dynamic analysis an attempt was made to utilize the data from the Mixed Company event to construct a simple but realistic loading function. Figure 69 shows the pressure waves that were chosen to model the external pressure acting on the arch at various locations. As was done in problems 4.4 and 4.5 the pressure was replaced by equivalent concentrated forces acting on 22 nodes.

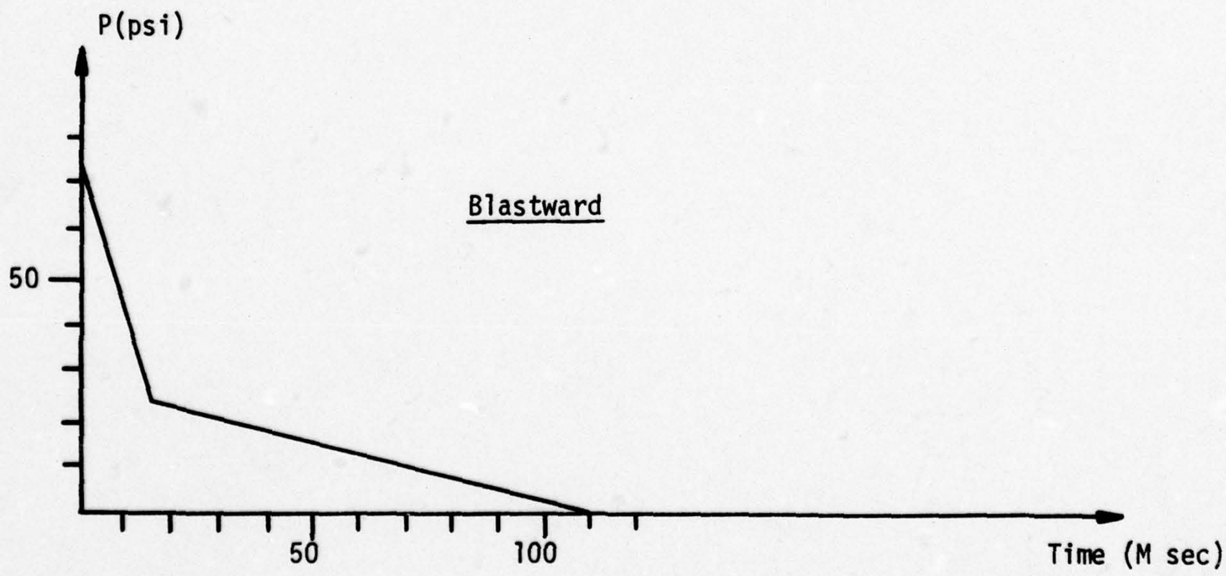
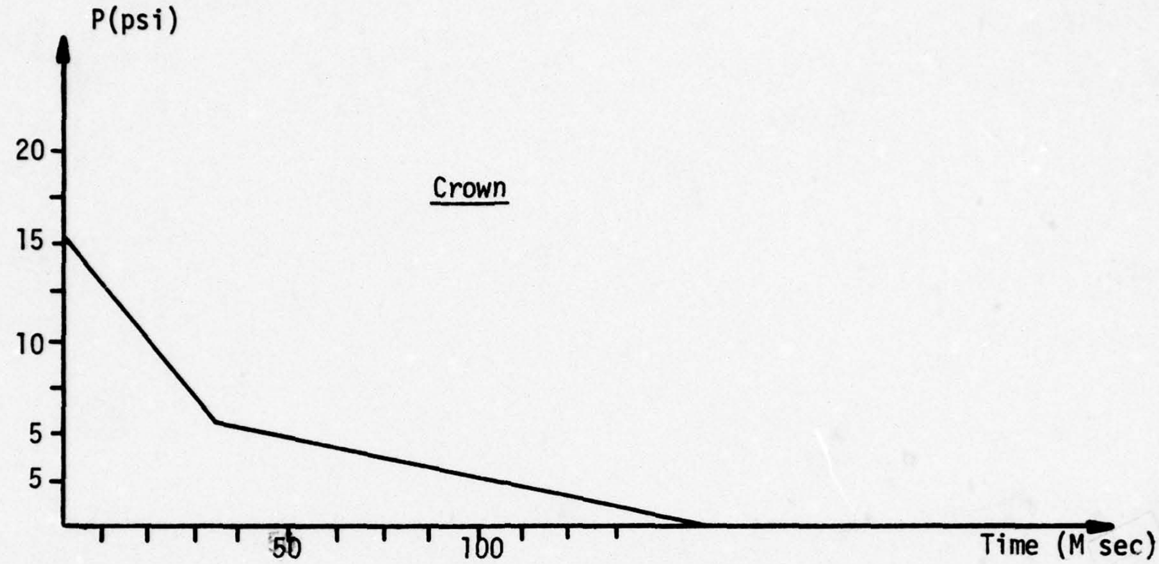


Figure 69. Applied Load - Arch



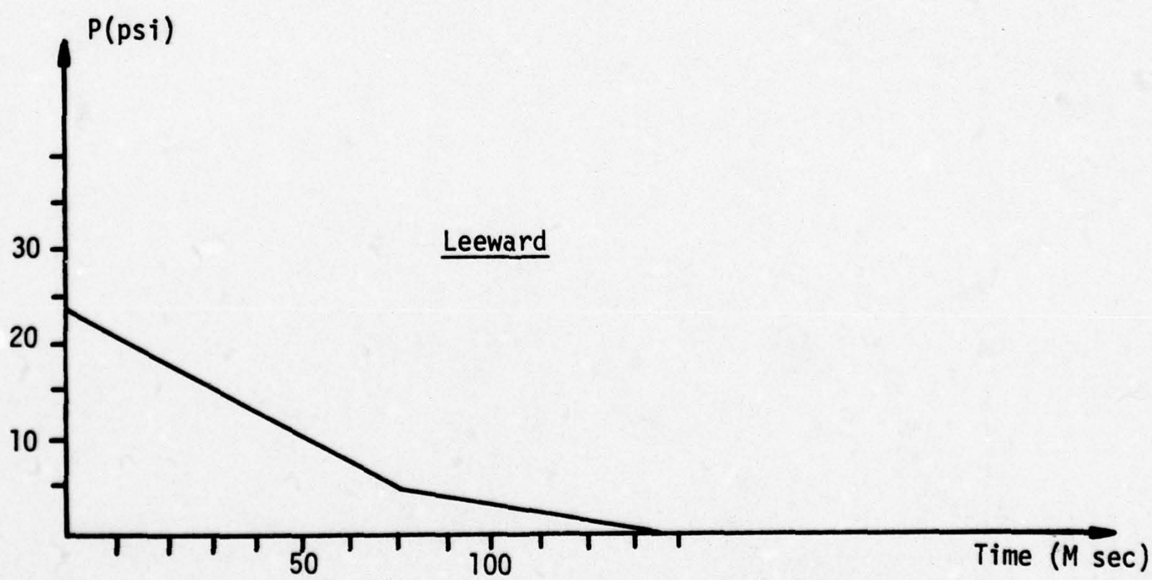


Figure 69. Applied Load - Arch (Concluded)

6.1.7 Dynamic Results

The first 15 eigenvalues of the 24-foot radius arch were extracted and the forced dynamic response obtained using modal superposition. The first five natural frequencies are ω_1 = 35.55 Rad/Sec, ω_2 = 77.33 Rad/Sec, ω_3 = 109.6 Rad/Sec, ω_4 = 156.9 Rad/Sec and ω_5 = 229.7 Rad/Sec.

The nodal displacements corresponding to the first natural frequency of vibration are for selected nodes:

NODE	X	Z
27	+0.0096	+0.0019
28	0	0
29	-0.0096	-0.0019
40	+0.0102	0
41	0	0
42	-0.0102	0
53	+0.0096	-0.0019
54	0	0
55	-0.0096	+0.0019

These nodes are located symmetrically about the crown of the arch. The displacements listed above indicate that the first natural frequency of 35.55 Rad/Sec corresponds to a torsional mode which would not be present in an actual shell.

6.2 Dynamic Analysis of a Hardened Aircraft Shelter with No End Walls

6.2.1 Introduction

A hardened aircraft shelter modeled after the shelter placed 600 feet from ground zero in the Mixed Company Event was analyzed by the SAP IV computer program. The 72-foot long, 24-foot internal radius shelter had the same cross-section as the arch described in problem 6.1.

6.2.2 Finite Element Model

The shelter was modeled with 15 node thick shell elements similar to those used in problem 6.1. The assignment of nodes and elements for the model is shown in Figure 70. It should be noted that symmetry was invoked so that one-half of the shelter was modeled with 15 elements, each of which was 12 feet wide. Cylindrical coordinates were used to input the nodal coordinates.

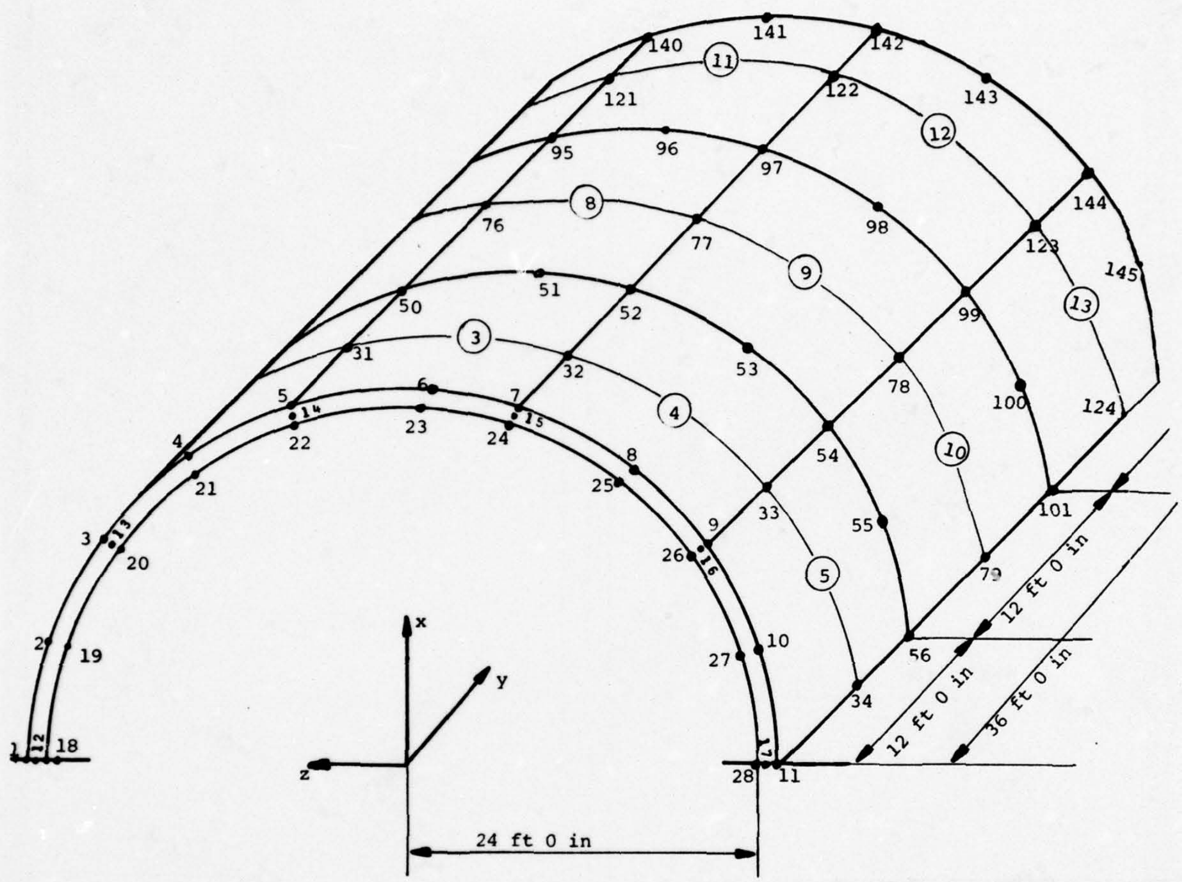


Figure 70. Element Assignment - Aircraft Shelter With No Endwalls

6.2.3 Dynamic Analysis

For the dynamic analysis the shelter was struck by the same pressure waves as those used for the arch in problem 6.1. The pressure wave was replaced by equivalent concentrated forces acting on 36 nodes.

Input Data - 24-Foot Radius by 72-Foot Hardened Shelter (Continued)

```
XYZT(53)=314.25,144.,54.,0.,          XYZT(54)=314.25,144.,36.,
XYZT(55)=314.25,144.,18.,0.,          XYZT(56)=314.25,144.,0.,
XYZT(57)=301.125,144.,180.,0.,        XYZT(58)=301.125,144.,144.,
XYZT(59)=301.125,144.,108.,0.,        XYZT(60)=301.125,144.,72.,
XYZT(61)=301.125,144.,36.,0.,         XYZT(62)=301.125,144.,
XYZT(63)=288.,144.,180.,0.,           XYZT(64)=288.,144.,162.,
XYZT(65)=288.,144.,144.,0.,           XYZT(66)=288.,144.,126.,
XYZT(67)=288.,144.,108.,0.,           XYZT(68)=288.,144.,90.,
XYZT(69)=288.,144.,72.,0.,            XYZT(70)=288.,144.,54.,
XYZT(71)=288.,144.,36.,0.,            XYZT(72)=288.,144.,18.,
XYZT(73)=288.,144.,0.,0.,             XYZT(74)=314.25,216.,180.,
XYZT(75)=314.25,216.,144.,0.,         XYZT(76)=314.25,216.,108.,
XYZT(77)=314.25,216.,72.,0.,          XYZT(78)=314.25,216.,36.,
XYZT(79)=314.25,216.,0.,0.,           XYZT(80)=301.125,216.,162.,
XYZT(81)=301.125,216.,126.,0.,        XYZT(82)=301.125,216.,90.,0.,
XYZT(83)=301.125,216.,54.,0.,         XYZT(84)=301.125,216.,18.,
XYZT(85)=288.,216.,180.,0.,           XYZT(86)=288.,216.,144.,
XYZT(87)=288.,216.,108.,0.,           XYZT(88)=288.,216.,72.,
XYZT(89)=288.,216.,36.,0.,            XYZT(90)=288.,216.,0.,
XYZT(91)=314.25,288.,180.,0.,         XYZT(92)=314.25,288.,162.,
XYZT(93)=314.25,288.,144.,0.,         XYZT(94)=314.25,288.,126.,
XYZT(95)=314.25,288.,108.,0.,         XYZT(96)=314.25,288.,90.,
XYZT(97)=314.25,288.,72.,0.,          XYZT(98)=314.25,288.,54.,
XYZT(99)=314.25,288.,36.,0.,          XYZT(100)=314.25,288.,18.,
XYZT(101)=314.25,288.,0.,0.,          XYZT(102)=301.125,288.,180.,
XYZT(103)=301.125,288.,144.,0.,       XYZT(104)=301.125,288.,108.,
XYZT(105)=301.125,288.,72.,0.,        XYZT(106)=301.125,288.,36.,
XYZT(107)=301.125,288.,0.,0.,         XYZT(108)=288.,288.,180.,
XYZT(109)=288.,288.,162.,0.,          XYZT(110)=288.,288.,144.,
XYZT(111)=288.,288.,126.,0.,          XYZT(112)=288.,288.,108.,
XYZT(113)=288.,288.,90.,0.,           XYZT(114)=288.,288.,72.,
XYZT(115)=288.,288.,54.,0.,           XYZT(116)=288.,288.,36.,
XYZT(117)=288.,288.,18.,0.,           XYZT(118)=288.,288.,
XYZT(119)=314.25,360.,180.,0.,        XYZT(120)=314.25,360.,144.,
XYZT(121)=314.25,360.,108.,0.,        XYZT(122)=314.25,360.,72.,
XYZT(123)=314.25,360.,36.,0.,         XYZT(124)=314.25,360.,0.,
XYZT(125)=301.125,360.,162.,0.,       XYZT(126)=301.125,360.,126.,0.,
```

6.2.4 Input Data - 24-Foot Radius by 72-Foot Hardened Shelter

```
MODEX=1
HEADER=*24FT R X 70FT HARDENED SHELTER                                  *
NUMNP=170,NELTYP=1,NF=20,NDYN=1,
CT(1 163)=C
IX(1,11,12,17,18,28,29,34,40,45,46,56,57,62,63)=                        1,1,1,1,1,1,
IX(73,74,79,85,90,91,101,102,107,108,118,119,124,130,135,136)=          1,1,1,1,1,1,
IX(146,147,152,153,163,164,166,169)=                                    1,1,1,1,1,1,
IX(2 10,13 16,19 27)=                                                   0,1,0,1,1,1,
IX(30 33,35 39,41 44,47 55,64 72,75 78,80 84)=                          0,0,0,1,1,1,
IX(92 100,103 106,109 117,120 123,125 129,131 134,137 145)=             0,0,0,1,1,1,
IX(148 151,154 162)=                                                    0,0,0,1,1,1,
IX(58 61,86 89,165,167,168,170)=                                        0,0,0,0,0,0,
XYZT(1)=314.25,0.,180.,0.,             XYZT(2)=314.25,0.,162.,
XYZT(3)=314.25,0.,144.,0.,             XYZT(4)=314.25,0.,126.,
XYZT(5)=314.25,0.,108.,0.,             XYZT(6)=314.25,0.,90.,
XYZT(7)=314.25,0.,72.,0.,              XYZT(8)=314.25,0.,54.,
XYZT(9)=314.25,0.,36.,0.,              XYZT(10)=314.25,0.,18.,
XYZT(11)=314.25,0.,0.,0.,              XYZT(12)=301.125,0.,180.,
XYZT(13)=301.125,0.,144.,0.,           XYZT(14)=301.125,0.,108.,
XYZT(15)=301.125,0.,72.,0.,            XYZT(16)=301.125,0.,36.,
XYZT(17)=301.125,0.,0.,0.,             XYZT(18)=288.,0.,180.,
XYZT(19)=288.,0.,162.,0.,              XYZT(20)=288.,0.,144.,
XYZT(21)=288.,0.,126.,0.,              XYZT(22)=288.,0.,108.,
XYZT(23)=288.,0.,90.,0.,               XYZT(24)=288.,0.,72.,
XYZT(25)=288.,0.,54.,0.,               XYZT(26)=288.,0.,36.,
XYZT(27)=288.,0.,18.,0.,               XYZT(28)=288.,0.,0.,
XYZT(29)=314.25,72.,180.,0.,           XYZT(30)=314.25,72.,144.,
XYZT(31)=314.25,72.,108.,0.,           XYZT(32)=314.25,72.,72.,
XYZT(33)=314.25,72.,36.,0.,            XYZT(34)=314.25,72.,0.,
XYZT(35)=301.125,72.,162.,0.,          XYZT(36)=301.125,72.,126.,
XYZT(37)=301.125,72.,90.,0.,           XYZT(38)=301.125,72.,54.,
XYZT(39)=301.125,72.,18.,0.,           XYZT(40)=288.,72.,180.,
XYZT(41)=288.,72.,144.,0.,             XYZT(42)=288.,72.,108.,
XYZT(43)=288.,72.,72.,0.,              XYZT(44)=288.,72.,36.,
XYZT(45)=288.,72.,0.,0.,               XYZT(46)=314.25,144.,180.,
XYZT(47)=314.25,144.,162.,0.,          XYZT(48)=314.25,144.,144.,
XYZT(49)=314.25,144.,126.,0.,          XYZT(50)=314.25,144.,108.,
XYZT(51)=314.25,144.,90.,0.,           XYZT(52)=314.25,144.,72.,
```

Input Data - 24-Foot Radius by 72-Foot Hardened Shelter (Continued)

```
XYZT(127)=301.125,360.,90.,0.,              XYZT(128)=301.125,360.,54.,
XYZT(129)=301.125,360.,18.,0.,              XYZT(130)=288.,360.,180.,
XYZT(131)=288.,360.,144.,0.,                XYZT(132)=288.,360.,108.,
XYZT(133)=288.,360.,72.,0.,                 XYZT(134)=288.,360.,36.,
XYZT(135)=288.,360.,0.,0.,                  XYZT(136)=314.25,432.,180.,
XYZT(137)=314.25,432.,162.,0.,              XYZT(138)=314.25,432.,144.,
XYZT(139)=314.25,432.,126.,0.,              XYZT(140)=314.25,432.,108.,
XYZT(141)=314.25,432.,90.,0.,               XYZT(142)=314.25,432.,72.,
XYZT(143)=314.25,432.,54.,0.,               XYZT(144)=314.25,432.,36.,
XYZT(145)=314.25,432.,18.,0.,               XYZT(146)=314.25,432.,0.,
XYZT(147)=301.125,432.,180.,0.,             XYZT(148)=301.125,432.,144.,
XYZT(149)=301.125,432.,108.,0.,             XYZT(150)=301.125,432.,72.,
XYZT(151)=301.125,432.,36.,0.,              XYZT(152)=301.125,432.,0.,
XYZT(153)=288.,432.,180.,0.,                XYZT(154)=288.,432.,162.,
XYZT(155)=288.,432.,144.,0.,                XYZT(156)=288.,432.,126.,
XYZT(157)=288.,432.,108.,0.,                XYZT(158)=288.,432.,90.,
XYZT(159)=288.,432.,72.,0.,                 XYZT(160)=288.,432.,54.,
XYZT(161)=288.,432.,36.,0.,                 XYZT(162)=288.,432.,18.,
XYZT(163)=288.,432.,0.,0.,                  XYZT(164)=0.,432.,-169.282
XYZT(165)=88.997,432.,-169.282,0.,          XYZT(166)=0.,432.,0.,
XYZT(167)=88.997,432.,0., 0.,               XYZT(168)=233.997,432.,0.,
XYZT(169)=0.,432.,169.282,0.,               XYZT(170)=88.997,432.,169.282
NSOL21=15,NUMMAT=1,MAXNOD=21,NOPSET=1,INTRS=4,INTT=3
NTP(1)=1
WTDEN(1)=.08391
MASSDN(1)=2.1716E-4
MATEV(1,1)=0.,3.644E6,3.644E6,3.644E6,.17,.17,.17
MATGA(1,1)=1.557E6,1.557E6,1.557E6
SSORLS(1)=1,2,3,4,5,6,8
SHELL1(1 15)=,,1,,1
S1TO8(1)=3,1,46,48,20,18,63,65,             S9TO16(1)=2,29,47,30,19,40,64,41
S17TO21(1)=13,12,57,58,35
S1TO8(2)=5,3,48,50,22,20,65,67,             S9TO16(2)=4,30,49,31,21,41,66,42
S17TO21(2)=14,13,58,59,36
S1TO8(3)=7,5,50,52,24,22,67,69,             S9TO16(3)=6,31,51,32,23,42,68,43
S17TO21(3)=15,14,59,60,37
S1TO8(4)=9,7,52,54,26,24,69,71              S9TO16(4)=8,32,53,33,25,43,70,44
S17TO21(4)=16,15,60,61,38
S1TO8(5)=11,9,54,56,28,26,71,73             S9TO16(5)=10,33,55,34,27,44,72,45
```

Input Data - 24-Foot Radius by 72-Foot Hardened Shelter (Concluded)

```
S17TO21(5)=17,16,61,62,39
S1TO8(6)=48,46,91,93,65,63,108,110          S9TO16(6)=47,74,92,75,64,85,109,86
S17TO21(6)=58,57,102,103,80
S1TO8(7)=50,48,93,95,67,65,110,112          S9TO16(7)=49,75,94,76,66,86,111,87
S17TO21(7)=59,58,103,104,81
S1TO8(8)=52,50,95,97,69,67,112,114          S9TO16(8)=51,76,96,77,68,87,113,88
S17TO21(3)=60,59,104,105,82
S1TO8(9)=54,52,97,99,71,69,114,116          S9TO16(9)=53,77,98,78,70,88,115,89
S17TO21(9)=61,60,105,106,83
S1TO8(10)=56,54,99,101,73,71,116,118        S9TO16(10)=55,78,100,79,72,89,117,90
S17TO21(10)=62,61,106,107,84
S1TO8(11)=93,91,136,138,110,108,153,155
S9TO16(11)=92,119,137,120,109,130,154,131
S17TO21(11)=103,102,147,148,125
S1TO8(12)=95,93,138,140,112,110,155,157
S9TO16(12)=94,120,139,121,111,131,156,132
S17TO21(12)=104,103,148,149,126
S1TO8(13)=97,95,140,142,114,112,157,159
S9TO16(13)=96,121,141,122,113,132,158,133
S17TO21(13)=105,104,149,150,127
S1TO8(14)=99,97,142,144,116,114,159,161
S9TO16(14)=98,122,143,123,115,133,160,134
S17TO21(14)=106,105,150,151,128
S1TO8(15)=101,99,144,146,118,116,161,163
S9TO16(15)=100,123,145,124,117,134,162,135
S17TO21(15)=107,106,151,152,129
'
8.
X(2000.)A()
Y(2000.)A()
Z(2000.)A()
X(2000.)Y(2000.)A()
X(2000.)Z(2000.)A()
Y(2000.)Z(2000.)A()
X(2000.)Z(2000.)Y(2000.)A()
X(2000.)Y(2000.)Z(2000.)AN()
X(2000.)Y(2000.)Z(2000.)AE()
X(2000.)Y(2000.)Z(2000.)ANE()
'
```

6.2.5 Results

The first 20 eigenvalues and eigenvectors were determined and used in the nodal superposition. The first five natural frequencies are ω_1 = 81.1 Rad/Sec, ω_2 = 185.9 Rad/Sec, ω_3 = 240.8 Rad/Sec, ω_4 = 242.2 Rad/Sec, and ω_5 = 324.7 Rad/Sec.

For nodal points on the 24-foot radius arch and the 24 x 72 foot shelter located at similar locations near the crown (Figure 71), it can be seen that the response of the arch is quite similar to the response of the shelter, when subjected to the pressure load of problem 6.1.

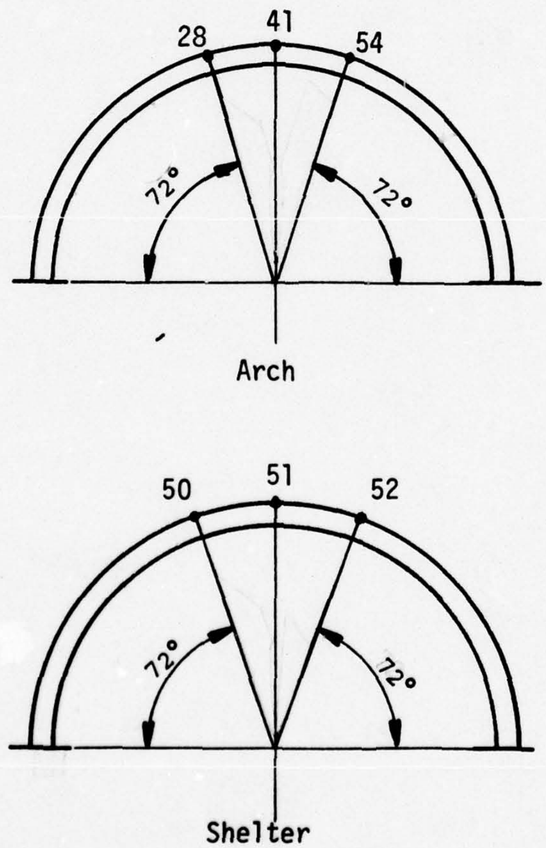


Figure 71. Comparable Nodes on Arch and Shelter

24 FOOT RADIUS ARCH

Node	Display	Max Value	Time @ Max
28	ΔX	0.3680	0.0300
28	ΔZ	0.5846	0.0280
41	ΔX	0.1690	0.0140
41	ΔZ	0.5024	0.0280
54	ΔX	0.3521	0.0720
54	ΔZ	0.5690	0.0280

24 x 72 FOOT SHELTER

Node	Display	Max Value	Time @ Max
50	ΔX	0.3875	0.0280
50	ΔZ	0.6308	0.0260
51	ΔX	0.1534	0.0140
51	ΔZ	0.5733	0.0260
52	ΔX	0.3511	0.0640
52	ΔZ	0.6106	0.0280

A mesh plot of the undeformed shelter is shown in Figure 72.

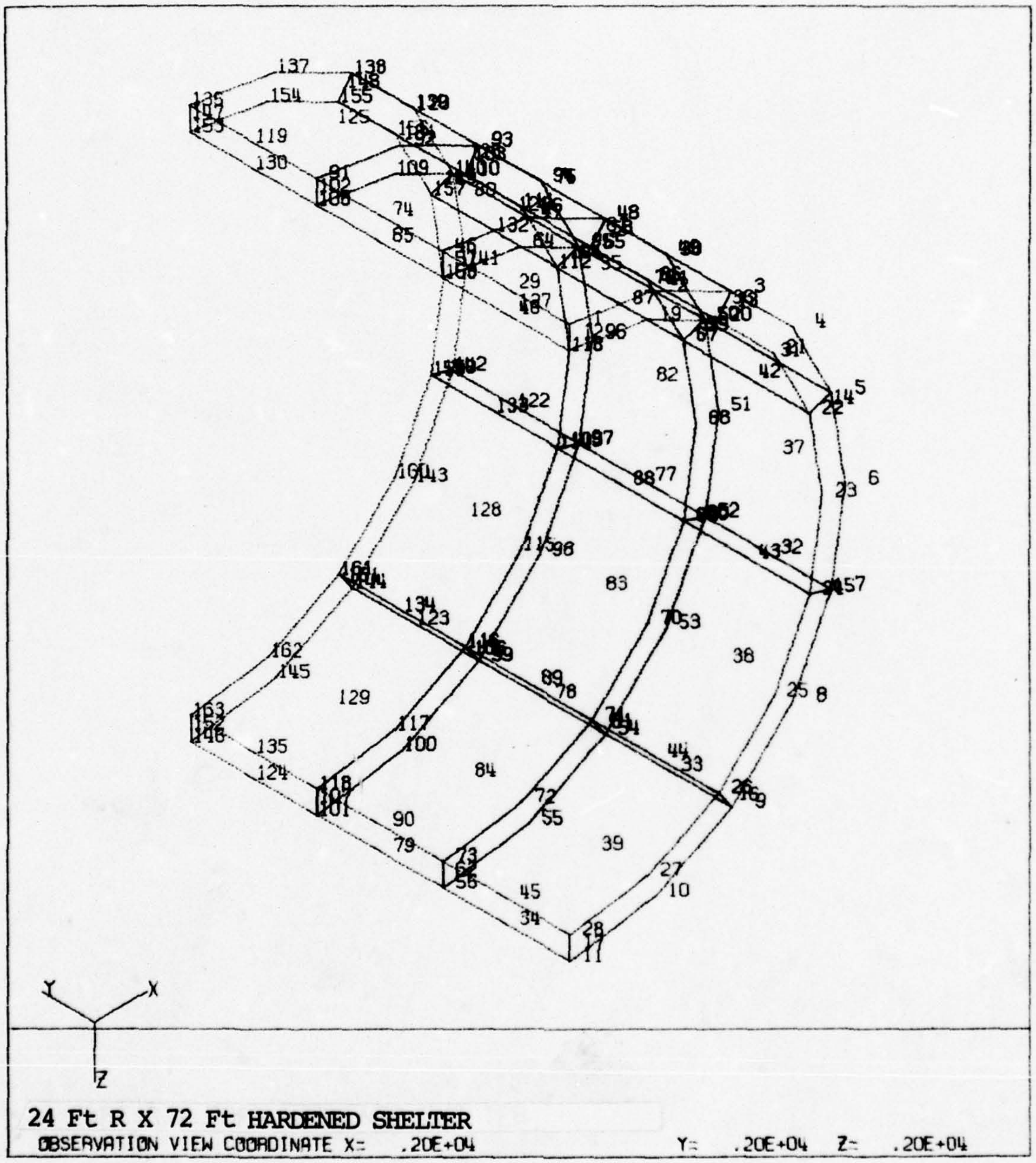


Figure 72. Mesh Plot - Hardened Shelter

6.3 Dynamic Analysis of a 24-Foot Radius by 72-Foot Long Hardened Shelter with Endwalls

6.3.1 Introduction

Fifteen-inch concrete endwalls were attached to the ends of the hardened shelter described in problem 6.1 and the shelter was reanalyzed using SAP IV.

6.3.2 Finite Element Model

An endwall, composed of 10-plate elements, was attached to the shelter model described in problem 6.1. Figure 73 shows the assignment of nodes and elements for the endwall. The endwall was placed at y=0 to be consistent with shelter that had been previously analyzed. Symmetry was again invoked.

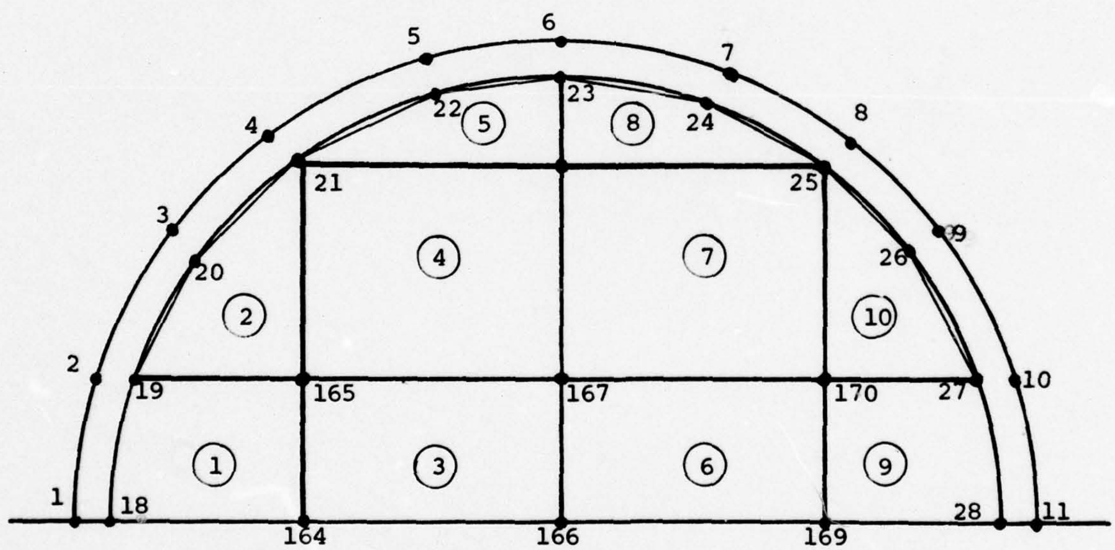


Figure 73. Element Assignment Shelter Endwall

6.3.3 Input Data - Hardened Shelter with Endwall

```
MODEX=1
HEADER=*24FT R X 70FT HARDENED SHELTER WITH ENDWALL                                  *
NUMNP=170,NELTYP=2,NF=20,NDYN=1,
CT(1 163)=C
IX(1,11,12,17,18,28,29,34,40,45,46,56,57,62,63)=                        1,1,1,1,1,1,
IX(73,74,79,85,90,91,101,102,107,108,118,119,124,130,135,136)=          1,1,1,1,1,1,
IX(146,147,152,153,163,164,166,169)=                                    1,1,1,1,1,1,
IX(2 10,13 16,19 27)=                                                   0,1,0,1,1,1,
IX(30 33,35 39,41 44,47 55,64 72,75 78,80 84)=                          0,0,0,1,1,1,
IX(92 100,103 106,109 117,120 123,125 129,131 134,137 145)=             0,0,0,1,1,1,
IX(148 151,154 162)=                                                    0,0,0,1,1,1,
IX(58 61,86 89,165,167,168,170)=                                        0,0,0,0,0,0,
XYZT(1)=314.25,0.,180.,0.,              XYZT(2)=314.25,0.,162.,
XYZT(3)=314.25,0.,144.,0.,              XYZT(4)=314.25,0.,126.,
XYZT(5)=314.25,0.,108.,0.,              XYZT(6)=314.25,0.,90.,
XYZT(7)=314.25,0.,72.,0.,               XYZT(8)=314.25,0.,54.,
XYZT(9)=314.25,0.,36.,0.,               XYZT(10)=314.25,0.,18.,
XYZT(11)=314.25,0.,0.,0.,               XYZT(12)=301.125,0.,180.,
XYZT(13)=301.125,0.,144.,0.,            XYZT(14)=301.125,0.,108.,
XYZT(15)=301.125,0.,72.,0.,             XYZT(16)=301.125,0.,36.,
XYZT(17)=301.125,0.,0.,0.,              XYZT(18)=288.,0.,180.,
XYZT(19)=288.,0.,162.,0.,               XYZT(20)=288.,0.,144.,
XYZT(21)=288.,0.,126.,0.,               XYZT(22)=288.,0.,108.,
XYZT(23)=288.,0.,90.,0.,                XYZT(24)=288.,0.,72.,
XYZT(25)=288.,0.,54.,0.,                XYZT(26)=288.,0.,36.,
XYZT(27)=288.,0.,18.,0.,                XYZT(28)=288.,0.,0.,
XYZT(29)=314.25,72.,180.,0.,            XYZT(30)=314.25,72.,144.,
XYZT(31)=314.25,72.,108.,0.,            XYZT(32)=314.25,72.,72.,
XYZT(33)=314.25,72.,36.,0.,             XYZT(34)=314.25,72.,0.,
XYZT(35)=301.125,72.,162.,0.,           XYZT(36)=301.125,72.,126.,
XYZT(37)=301.125,72.,90.,0.,            XYZT(38)=301.125,72.,54.,
XYZT(39)=301.125,72.,18.,0.,            XYZT(40)=288.,72.,180.,
XYZT(41)=288.,72.,144.,0.,              XYZT(42)=288.,72.,108.,
XYZT(43)=288.,72.,72.,0.,               XYZT(44)=288.,72.,36.,
XYZT(45)=288.,72.,0.,0.,                XYZT(46)=314.25,144.,180.,
XYZT(47)=314.25,144.,162.,0.,           XYZT(48)=314.25,144.,144.,
```

Input Data - Hardened Shelter with Endwall (Continued)

```
XYZT(49)=314.25,144.,126.,0.,         XYZT(50)=314.25,144.,108.,
XYZT(51)=314.25,144.,90.,0.,          XYZT(52)=314.25,144.,72.,
XYZT(53)=314.25,144.,54.,0.,          XYZT(54)=314.25,144.,36.,
XYZT(55)=314.25,144.,18.,0.,          XYZT(56)=314.25,144.,0.,
XYZT(57)=301.125,144.,180.,0.,        XYZT(58)=301.125,144.,144.,
XYZT(59)=301.125,144.,108.,0.,        XYZT(60)=301.125,144.,72.,
XYZT(61)=301.125,144.,36.,0.,         XYZT(62)=301.125,144.,
XYZT(63)=288.,144.,180.,0.,           XYZT(64)=288.,144.,162.,
XYZT(65)=288.,144.,144.,0.,           XYZT(66)=288.,144.,126.,
XYZT(67)=288.,144.,108.,0.,           XYZT(68)=288.,144.,90.,
XYZT(69)=288.,144.,72.,0.,            XYZT(70)=288.,144.,54.,
XYZT(71)=288.,144.,36.,0.,            XYZT(72)=288.,144.,18.,
XYZT(73)=288.,144.,0.,0.,             XYZT(74)=314.25,216.,180.,
XYZT(75)=314.25,216.,144.,0.,         XYZT(76)=314.25,216.,108.,
XYZT(77)=314.25,216.,72.,0.,          XYZT(78)=314.25,216.,36.,
XYZT(79)=314.25,216.,0.,0.,           XYZT(80)=301.125,216.,162.,
XYZT(81)=301.125,216.,126.,0.,        XYZT(82)=301.125,216.,90.,0.,
XYZT(83)=301.125,216.,54.,0.,         XYZT(84)=301.125,216.,18.,
XYZT(85)=288.,216.,180.,0.,           XYZT(86)=288.,216.,144.,
XYZT(87)=288.,216.,108.,0.,           XYZT(88)=288.,216.,72.,
XYZT(89)=288.,216.,36.,0.,            XYZT(90)=288.,216.,0.,
XYZT(91)=314.25,288.,180.,0.,         XYZT(92)=314.25,288.,162.,
XYZT(93)=314.25,288.,144.,0.,         XYZT(94)=314.25,288.,126.,
XYZT(95)=314.25,288.,108.,0.,         XYZT(96)=314.25,288.,90.,
XYZT(97)=314.25,288.,72.,0.,          XYZT(98)=314.25,288.,54.,
XYZT(99)=314.25,288.,36.,0.,          XYZT(100)=314.25,288.,18.,
XYZT(101)=314.25,288.,0.,0.,          XYZT(102)=301.125,288.,180.,
XYZT(103)=301.125,288.,144.,0.,       XYZT(104)=301.125,288.,108.,
XYZT(105)=301.125,288.,72.,0.,        XYZT(106)=301.125,288.,36.,
XYZT(107)=301.125,288.,0.,0.,         XYZT(108)=288.,288.,180.,
XYZT(109)=288.,288.,162.,0.,          XYZT(110)=288.,288.,144.,
XYZT(111)=288.,288.,126.,0.,          XYZT(112)=288.,288.,108.,
XYZT(113)=288.,288.,90.,0.,           XYZT(114)=288.,288.,72.,
XYZT(115)=288.,288.,54.,0.,           XYZT(116)=288.,288.,36.,
XYZT(117)=288.,288.,18.,0.,           XYZT(118)=288.,288.,
```

Input Data - Hardened Shelter with Endwall (Continued)

```
XYZT(119)=314.25,360.,180.,0.,          XYZT(120)=314.25,360.,144.,
XYZT(121)=314.25,360.,108.,0.,          XYZT(122)=314.25,360.,72.,
XYZT(123)=314.25,360.,36.,0.,           XYZT(124)=314.25,360.,0.,
XYZT(125)=301.125,360.,162.,0.,         XYZT(126)=301.125,360.,126.,0.,
XYZT(127)=301.125,360.,90.,0.,          XYZT(128)=301.125,360.,54.,
XYZT(129)=301.125,360.,18.,0.,          XYZT(130)=288.,360.,180.,
XYZT(131)=288.,360.,144.,0.,            XYZT(132)=288.,360.,108.,
XYZT(133)=288.,360.,72.,0.,             XYZT(134)=288.,360.,36.,
XYZT(135)=288.,360.,0.,0.,              XYZT(136)=314.25,432.,180.,
XYZT(137)=314.25,432.,162.,0.,          XYZT(138)=314.25,432.,144.,
XYZT(139)=314.25,432.,126.,0.,          XYZT(140)=314.25,432.,108.,
XYZT(141)=314.25,432.,90.,0.,           XYZT(142)=314.25,432.,72.,
XYZT(143)=314.25,432.,54.,0.,           XYZT(144)=314.25,432.,36.,
XYZT(145)=314.25,432.,18.,0.,           XYZT(146)=314.25,432.,0.,
XYZT(147)=301.125,432.,180.,0.,         XYZT(148)=301.125,432.,144.,
XYZT(149)=301.125,432.,108.,0.,         XYZT(150)=301.125,432.,72.,
XYZT(151)=301.125,432.,36.,0.,          XYZT(152)=301.125,432.,0.,
XYZT(153)=288.,432.,180.,0.,            XYZT(154)=288.,432.,162.,
XYZT(155)=288.,432.,144.,0.,            XYZT(156)=288.,432.,126.,
XYZT(157)=288.,432.,108.,0.,            XYZT(158)=288.,432.,90.,
XYZT(159)=288.,432.,72.,0.,             XYZT(160)=288.,432.,54.,
XYZT(161)=288.,432.,36.,0.,             XYZT(162)=288.,432.,18.,
XYZT(163)=288.,432.,0.,0.,              XYZT(164)=0.,432.,-169.282
XYZT(165)=88.997,432.,-169.282,0.,      XYZT(166)=0.,432.,0.,
XYZT(167)=88.997,432.,0., 0.,           XYZT(168)=233.997,432.,0.,
XYZT(169)=0.,432.,169.282,0.,           XYZT(170)=88.997,432.,169.282
NPLATE=10,PNDM=1
PMPI(1)=2.17E-4,,,,3.752E6,6.379E5,0.,3.752E6,0.,1.557E6
PLATE(1 10)=15.
IPLATE(1)=153,164,165,154
IPLATE(2)=154,165,156,155
IPLATE(3)=164,166,167,165
IPLATE(4)=165,167,168,156
IPLATE(5)=156,168,158,157
IPLATE(6)=166,169,170,167
```

Input Data - Hardened Shelter with Endwall (Continued)

```
IPLATE(7)=167,170,160,168
IPLATE(8)=168,160,159,158
IPLATE(9)=169,163,162,170
IPLATE(10)=170,162,161,160
NSOL21=15,NUMMAT=1,MAXNOD=21,NOPSET=1,INTRS=4,INTT=3
NTP(1)=1
WTDEN(1)=.08391
MASSDN(1)=2.1716E-4
MATEV(1,1)=0.,3.644E6,3.644E6,3.644E6,.17,.17,.17
MATGA(1,1)=1.557E6,1.557E6,1.557E6
SSORLS(1)=1,2,3,4,5,6,8
SHELL1(1 15)=,,1,,1
S1TO8(1)=3,1,46,48,20,18,63,65,         S9TO16(1)=2,29,47,30,19,40,64,41
S17TO21(1)=13,12,57,58,35
S1TO8(2)=5,3,48,50,22,20,65,67,         S9TO16(2)=4,30,49,31,21,41,66,42
S17TO21(2)=14,13,58,59,36
S1TO8(3)=7,5,50,52,24,22,67,69,         S9TO16(3)=6,31,51,32,23,42,68,43
S17TO21(3)=15,14,59,60,37
S1TO8(4)=9,7,52,54,26,24,69,71          S9TO16(4)=8,32,53,33,25,43,70,44
S17TO21(4)=16,15,60,61,38
S1TO8(5)=11,9,54,56,28,26,71,73         S9TO16(5)=10,33,55,34,27,44,72,45
S17TO21(5)=17,16,61,62,39
S1TO8(6)=48,46,91,93,65,63,108,110      S9TO16(6)=47,74,92,75,64,85,109,86
S17TO21(6)=58,57,102,103,80
S1TO8(7)=50,48,93,95,67,65,110,112      S9TO16(7)=49,75,94,76,66,86,111,87
S17TO21(7)=59,58,103,104,81
S1TO8(8)=52,50,95,97,69,67,112,114      S9TO16(8)=51,76,96,77,68,87,113,88
S17TO21(8)=60,59,104,105,82
S1TO8(9)=54,52,97,99,71,69,114,116      S9TO16(9)=53,77,98,78,70,88,115,89
S17TO21(9)=61,60,105,106,83
S1TO8(10)=56,54,99,101,73,71,116,118    S9TO16(10)=55,78,100,79,72,89,117,90
S17TO21(10)=62,61,106,107,84
S1TO8(11)=93,91,136,138,110,108,153,155
S9TO16(11)=92,119,137,120,109,130,154,131
S17TO21(11)=103,102,147,148,125
S1TO8(12)=95,93,138,140,112,110,155,157
S9TO16(12)=94,120,139,121,111,131,156,132
```

Input Data - Hardened Shelter with Endwall (Concluded)

```
S17TO21(12)=104,103,148,149,126
S1TO8(13)=97,95,140,142,114,112,157,159
S9TO16(13)=96,121,141,122,113,132,158,133
S17TO21(13)=105,104,149,150,127
S1TO8(14)=99,97,142,144,116,114,159,161
S9TO16(14)=98,122,143,123,115,133,160,134
S17TO21(14)=106,105,150,151,128
S1TO8(15)=101,99,144,146,118,116,161,163
S9TO16(15)=100,123,145,124,117,134,162,135
S17TO21(15)=107,106,151,152,129
'
8.
X(2000.)A()
Y(2000.)A()
Z(2000.)A()
X(2000.)Y(2000.)A()
X(2000.)Z(2000.)A()
Y(2000.)Z(2000.)A()
X(2000.)Z(2000.)Y(2000.)A()
X(2000.)Y(2000.)Z(2000.)AN()
X(2000.)Y(2000.)Z(2000.)AE()
X(2000.)Y(2000.)Z(2000.)ANE()
'
```

The shelter with endwalls was struck by the same pressure wave as described in problem 4.4 and 6.2. No pressure has been applied to the endwall so that a comparison might be made.

The first five natural frequencies are ω_1 = 126.2 Rad/Sec, ω_2= 203.0 Rad/Sec, ω_3 = 236.5 Rad/Sec, ω_4 = 330.4 Rad/Sec, and ω_5 = 349.9 Rad/Sec. The slightly higher natural frequencies confirm that the shelter with endwalls is indeed slightly stiffer than the open-ended shelter. The eigenvalues and eigenvectors were used in the subsequent mode superposition analysis.

The maximum displacements due to the pressure waves at a point 24 feet from the end wall (y = 144 in) for the two shelters that were analyzed are:

24 x 72 ft Shelter

Node	Displacement	Max Value	Time at Max
50	ΔX	0.3875	0.0280
50	ΔZ	0.6308	0.0260
51	ΔX	0.1534	0.0140
51	ΔZ	0.5733	0.0260
52	ΔX	0.3511	0.0640
52	ΔZ	0.6106	0.0280

24 x 72 ft Shelter
With Endwall at y = 432 in

Node	Displacement	Max Value	Time at Max
50	ΔX	0.2323	0.0240
50	ΔZ	0.3110	0.0220
51	ΔX	0.1279	0.0120
51	ΔZ	0.2728	0.0220
52	ΔX	0.2165	0.0160
52	ΔZ	0.2974	0.0200

It can be seen that when the shelter is struck by a dynamic load the endwall has a significant stiffening effect.

Figures 74 and 75 show two views of the element layout for the hardened shelter with endwalls. These plots were produced using the mesh plot routine of Appendix C.

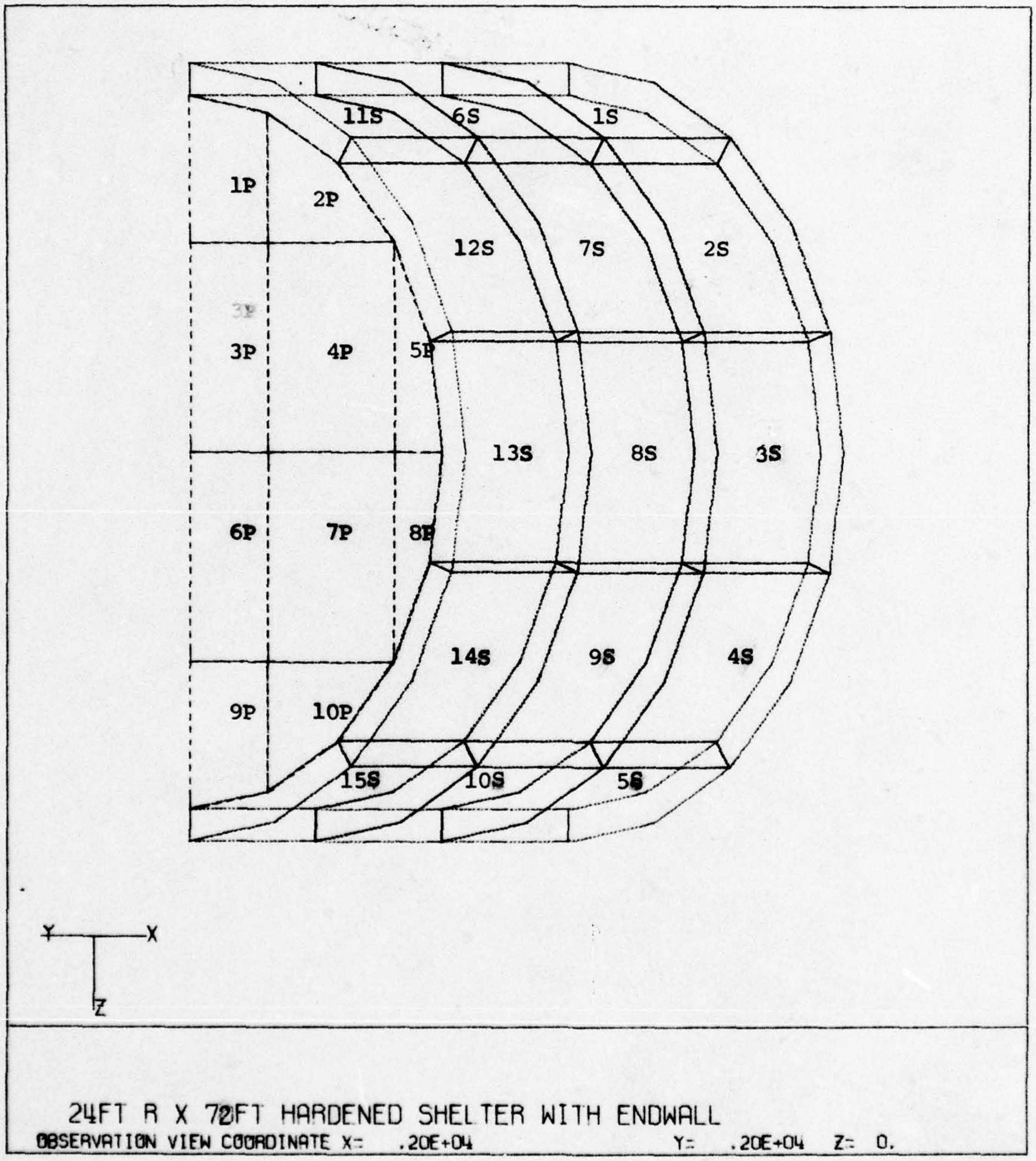


Figure 74. View 1 of Hardened Shelter with Endwall

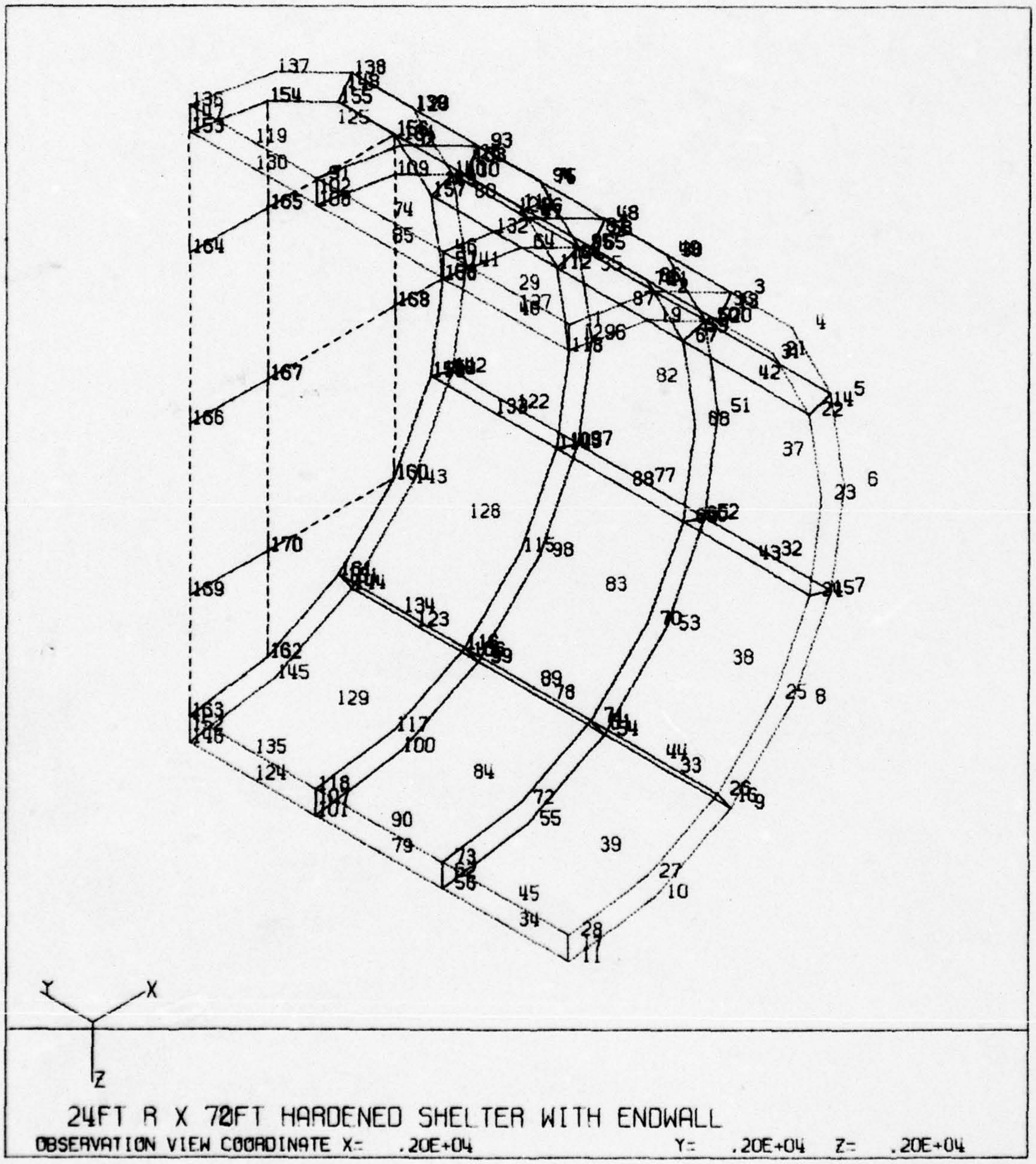


Figure 75. View 2 of Hardened Shelter with Endwall

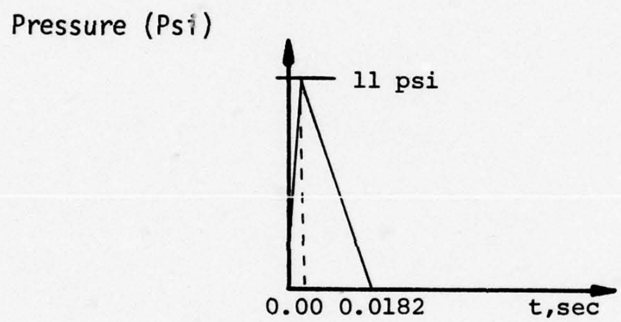
6.4 Application of SAP IV to a Prowed Door

6.4.1 Loading

A prow-shaped rolling TAB-VEE door is subjected to the following loads:

Case 1 - Static uniform pressure

Case 2 - Dynamic uniform pressure with the time history shown in Figure 76.



Loading Function

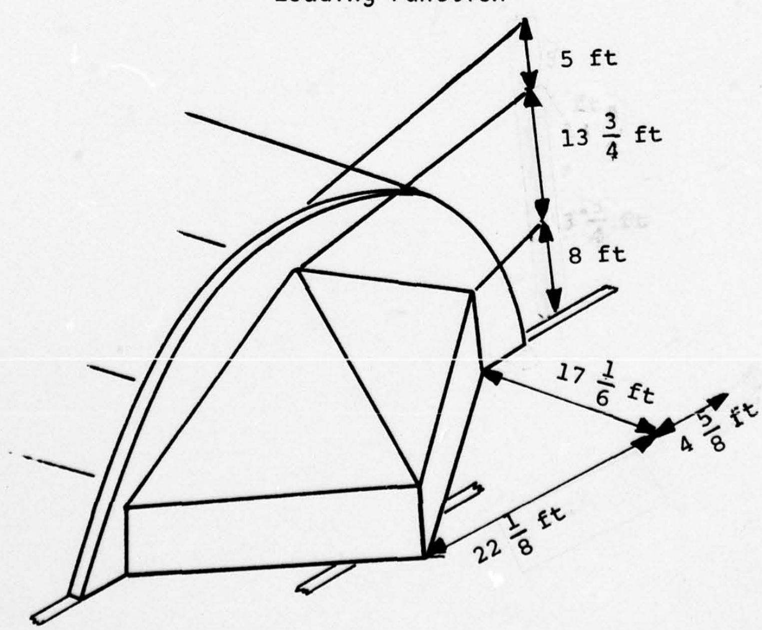


Figure 76. Prow-shaped Rolling TAB-VEE Door

6.4.2 Finite Element Model

The prow-shaped TAB-VEE door consists of three parts: collar bulkhead, armor door, and floor frame. The finite element model for this structure, shown in the following diagrams, includes three groups of elements: thick shell, thin plate, and beam elements. The thick shell and the quadrilateral thin plate elements are used to represent the bulkhead (Figure 77) and the armor door (Figure 78), respectively. The beam elements are used to model the reinforcing ribs and the floor frame (Figure 79). Also, because of symmetry only half of the door has to be modeled with symmetry conditions imposed to the center plane of the door.

The dynamic calculation was performed in two parts. The first set of data for the dynamic calculation generates the eigenvalues of the armored door and writes a restart tape. The second set of data causes SAP IV to read the restart tape and generate the model solution using the calculated eigenvalues.

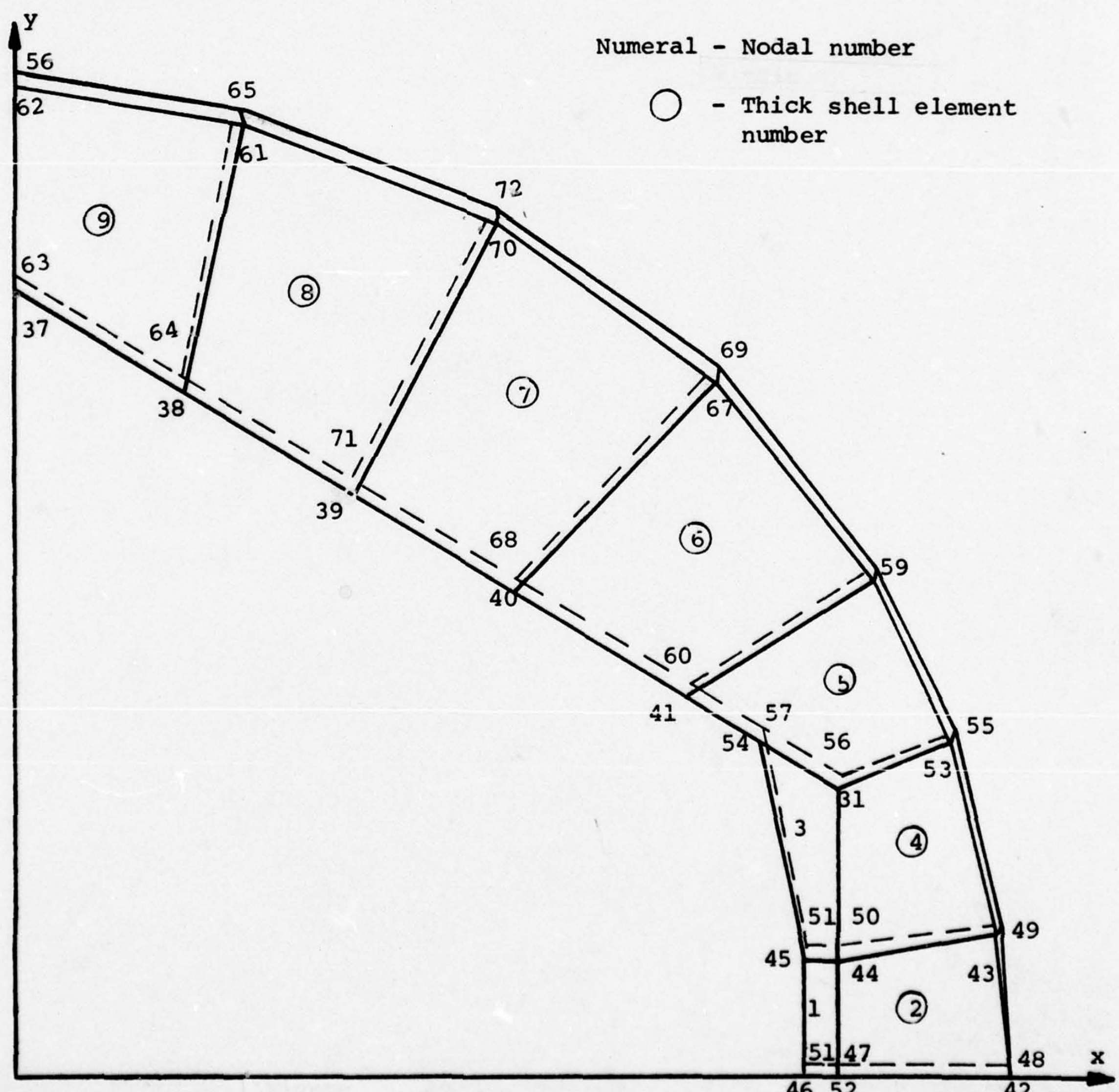


Figure 77. Bulkhead

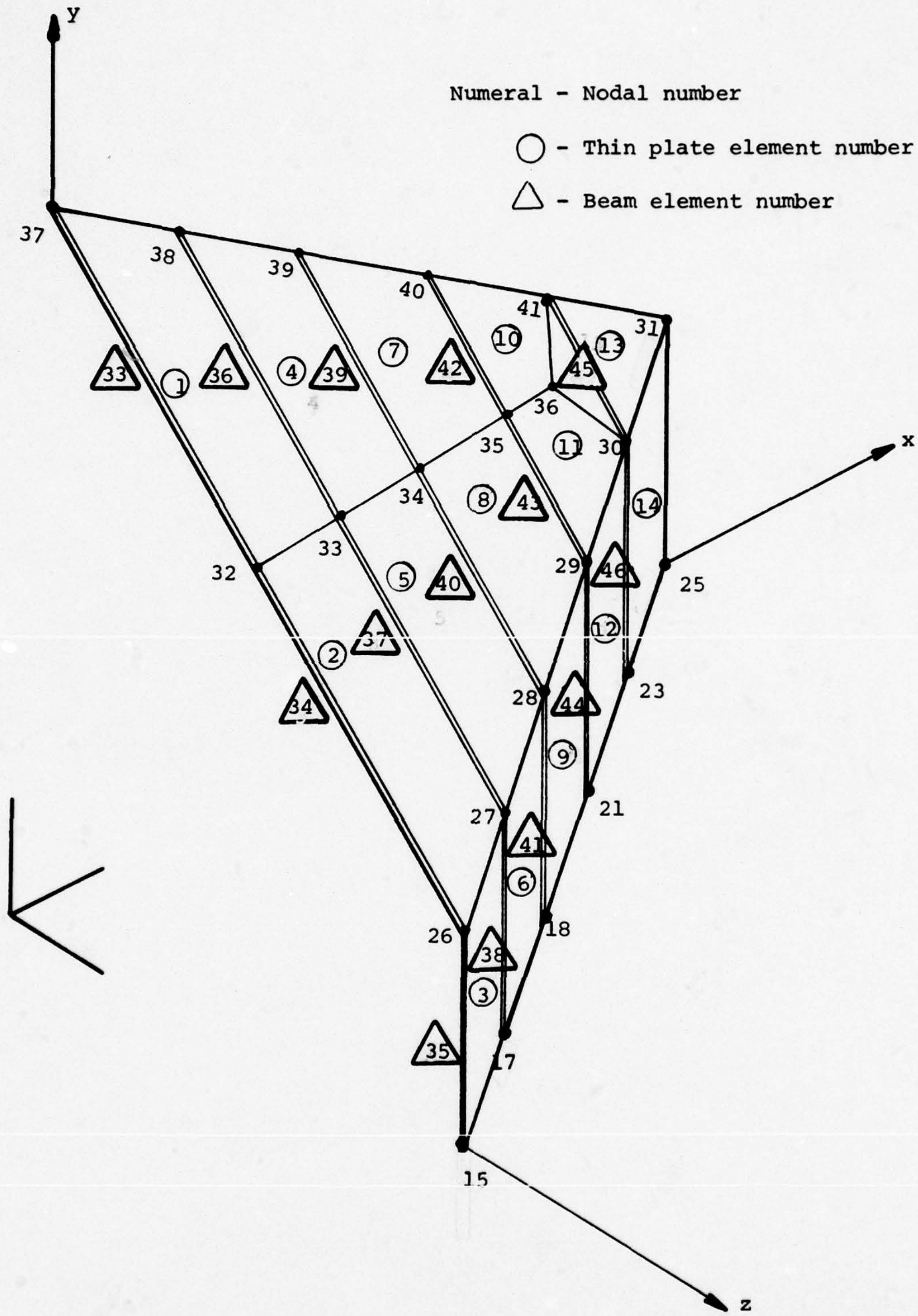


Figure 78. Armor Door

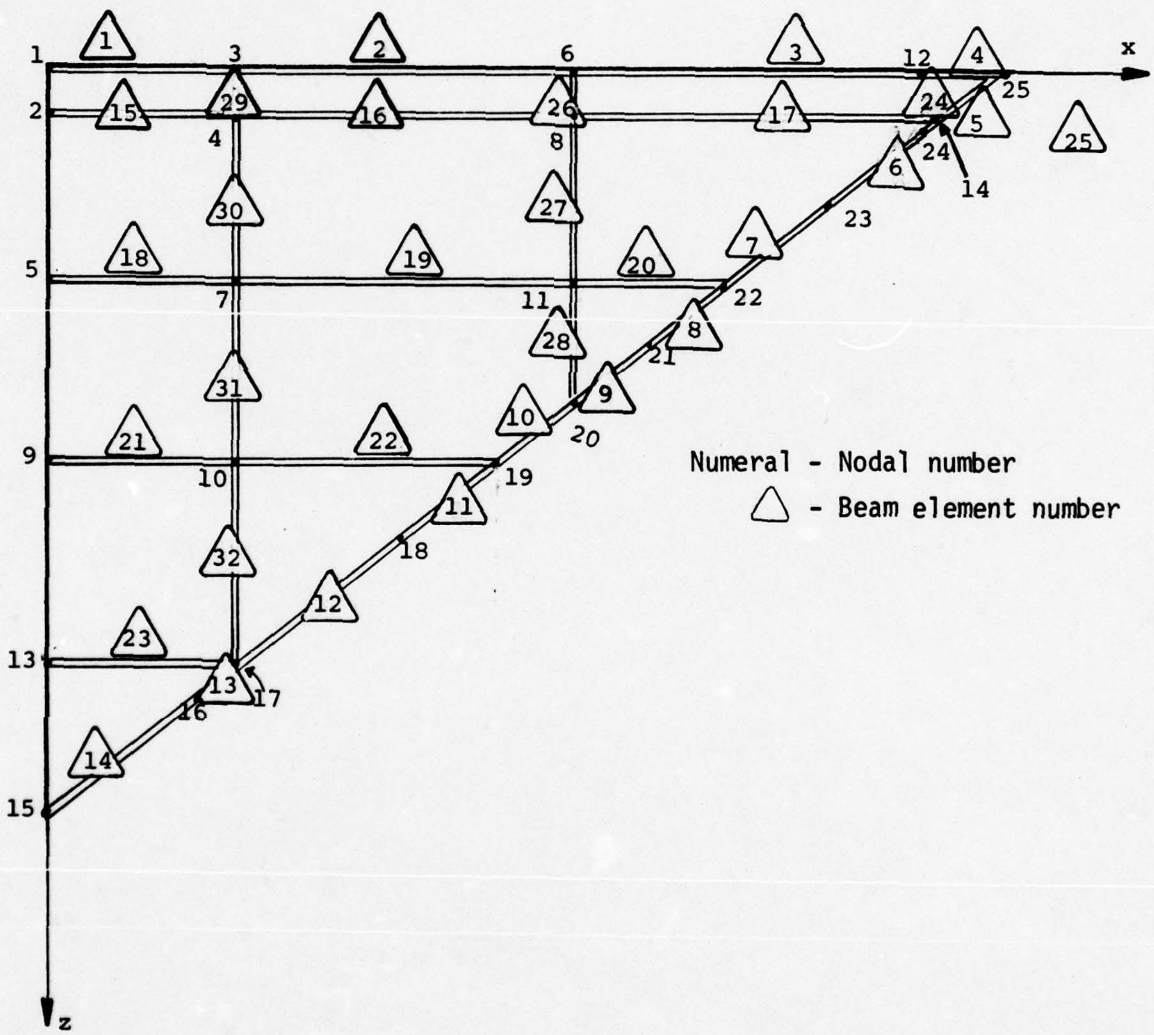


Figure 79. Floor Frame

6.4.3 Input Data - Static Uniform Pressure on One Side of Door (Continued)

```
MODEX=1
HEADER=*STATIC ANALYSIS OF A PROWED ARMOR DOOR                                *
NUMNP=72,NELTYP=3,LL=1
IX(1,13)=                                                          1,1,1,0,0,1,
IX(2,5,9,15,26,32,37)=                                             1,0,0,0,0,1,
IX(3,6,12,16,25)=                                                  0,1,1,0,0,0,
IX(4,7,8,10,11,14,17 24,27 31,33 36,38 41,44)=                     0,0,0,0,0,0,
IX(42,46,47,52)=                                                   0,1,1,1,1,1,
IX(43,45,50,51,33,54,56 58,60,61,64,67,68,70,71)=                  0,0,0,1,1,1,
IX(48,49,55,59,65,69,72)=                                          0,0,1,1,1,1,
IX(62,63)=                                                         1,0,0,1,1,1,
IX(66)=                                                            1,0,1,1,1,1,
XYZT(1)=0.,0.,0.,0.,                 XYZT(2)=0.,0.,10.125
XYZT(3)=48.,0.,0.,0.,                XYZT(4)=48.,0.,10.125
XYZT(5)=0.,0.,60.,0.,                XYZT(6)=144.,
XYZT(7)=48.,0.,60.,0.,               XYZT(8)=144.,0.,10.125
XYZT(9)=0.,0.,110.,0.,               XYZT(10)=48.,0.,110.,
XYZT(11)=144.,0.,60.,0.,             XYZT(12)=250.94,
XYZT(13)=0.,0.,168.757,0.,           XYZT(14)=250.94,0.,10.125
XYZT(15)=0.,0.,206.,0.,              XYZT(16)=48.,0.,168.757
XYZT(17)=53.1,0.,164.8,0.,           XYZT(18)=106.2,0.,123.6,
XYZT(19)=123.728,0.,110.,0.,         XYZT(20)=144.,0.,94.271,
XYZT(21)=159.3,0.,82.4,0.,           XYZT(22)=188.1699,0.,60.,
XYZT(23)=212.4,0.,41.2,0.,           XYZT(24)=250.94,0.,11.297
XYZT(25)=265.5,0.,0.,0.,             XYZT(26)=0.,96.,206.,
XYZT(27)=53.15,96.,164.8,0.,         XYZT(28)=106.2,96.,123.6
XYZT(29)=159.3,96.,82.4,0.,          XYZT(30)=212.4,96.,41.2,
XYZT(31)=265.5,96.,0.,0.,            XYZT(32)=0.,178.5,103.,
XYZT(33)=53.1,162.,82.4,0.,          XYZT(34)=106.2,145.5,61.8,
XYZT(35)=159.32,129.,41.2,0.,        XYZT(36)=199.125,116.625,25.75
XYZT(37)=0.,261.,0.,0.,              XYZT(38)=53.1,228.,
XYZT(39)=106.2,195.,0.,0.,           XYZT(40)=159.3,162.,
XYZT(41)=212.4,129.,0.,0.,           XYZT(42)=321.,
XYZT(43)=317.42,47.82,0.,0.,         XYZT(44)=265.5,40.,
```

Input Data - Static Uniform Pressure on One Side of Door (Continued)

```
XYZT(45)=250.94,40.,0.,0.,
XYZT(47)=265.5,0.,-5.8,0.,
XYZT(49)=317.42,47.82,-5.8,0.,
XYZT(51)=250.94,40.,-5.8,0.,
XYZT(53)=301.87,109.15,0.,0.,
XYZT(55)=301.87,109.15,-5.8,0.,
XYZT(57)=238.95,112.5,-5.8,0.,
XYZT(59)=274.36,166.63,-5.8,0.,
XYZT(61)=72.81,312.63,0.,0.,
XYZT(63)=0.,261.,-5.8,0.,
XYZT(65)=72.81,312.63,-5.8,0.,
XYZT(67)=225.06,228.88,0.,0.,
XYZT(69)=225.06,228.88,-5.8,0.,
XYZT(71)=106.2,195.,-5.8,0.,
NBEAM=46,BNEPC=8,BNMPC=1
BMPC(1)=3.0E7,.3,7.36E-4,
BEPC(1)=11.7,,,284.,179.,179.
BEPC(2)=5.54,,,25.,54.2,3.8
BEPC(3)=2.51,,,.033,14.8,1.98
BEPC(4)=2.12,,,.534,110.,37.
BEPC(5)=3.16,,,141.97,88.1,88.1
BEPC(6)=7.35,,,0.463,53.3,17.1
BEPC(7)=0.01,,,1000.,1.,1.
BEPC(8)=0.01,,,1.,1.,1.
BEAM(1)=1,3,2,1,1
BEAM(2)=3,6,2,1,1,
BEAM(3)=6,12,2,1,1
BEAM(4)=12,25,2,1,1
BEAM(5)=24,25,2,1,5
BEAM(6)=23,24,2,1,5
BEAM(7)=22,23,2,1,5
BEAM(8)=21,22,2,1,5
BEAM(9)=20,21,2,1,5
BEAM(10)=19,20,2,1,5
BEAM(11)=18,19,2,1,5
```

```
XYZT(46)=250.94
XYZT(48)=321.,0.,-5.8
XYZT(50)=265.5,40.,-5.8
XYZT(52)=250.94,0.,-5.8
XYZT(54)=238.95,112.5
XYZT(56)=265.5,96.,-5.8
XYZT(58)=274.36,166.63,
XYZT(60)=212.4,129.63,-5.8,
XYZT(62)=0.,321.,
XYZT(64)=53.8,228.,-5.8
XYZT(66)=0.,321.,-5.8
XYZT(68)=159.3,162.,-5.8
XYZT(70)=153.53,281.9,
XYZT(72)=153.53,281.9,-5.8
```

Input Data - Static Uniform Pressure on One Side of Door (Continued)

```
BEAM(12)=17,18,2,1,5
BEAM(13)=16,17,2,1,5
BEAM(14)=15,16,2,1,5
BEAM(15)=2,4,1,1,2
BEAM(16)=4,8,1,1,2
BEAM(17)=8,14,1,1,2
BEAM(18)=5,7,1,1,3
BEAM(19)=7,11,1,1,3
BEAM(20)=11,22,1,1,3
BEAM(21)=9,10,1,1,3
BEAM(22)=10,19,1,1,3
BEAM(23)=13,16,1,1,4
BEAM(24)=12,14,1,1,5
BEAM(25)=12,24,1,1,5
BEAM(26)=6,8,1,1,6
BEAM(27)=8,11,1,1,6
BEAM(28)=11,20,1,1,6
BEAM(29)=3,4,1,1,6
BEAM(30)=4,7,1,1,6
BEAM(31)=7,10,1,1,6
BEAM(32)=10,16,1,1,6
BEAM(33)=37,32,15,1,7
BEAM(34)=32,26,15,1,7
BEAM(35)=26,15,37,1,7
BEAM(36)=38,33,17,1,8
BEAM(37)=33,27,17,1,8
BEAM(38)=27,17,38,1,8
BEAM(39)=39,34,18,1,8
BEAM(40)=34,28,18,1,8
BEAM(41)=28,18,39,1,8
BEAM(42)=40,35,21,1,8
BEAM(43)=35,29,21,1,8
BEAM(44)=29,21,40,1,8
BEAM(45)=41,30,23,1,8
BEAM(46)=30,23,41,1,8
PMPI(1)=7.36E-4,,,,3.375E7,1.125E7,,3.375E7,,1.125E7
PELML=1.
```

Input Data - Static Uniform Pressure on One Side of Door (Continued)

```
NPLATE=14,PNDM=1
PLATE(1 14)=.875,-11.
IPLATE(1)=37,32,33,38
IPLATE(2)=32,26,27,33
IPLATE(3)=26,15,17,27
IPLATE(4)=38,33,34,39
IPLATE(5)=33,27,28,34
IPLATE(6)=27,17,18,28
IPLATE(7)=39,34,35,40
IPLATE(8)=34,28,29,35
IPLATE(9)=28,18,21,29
IPLATE(10)=40,35,36,41
IPLATE(11)=35,29,30,36
IPLATE(12)=29,21,23,30
IPLATE(13)=41,36,30,31
IPLATE(14)=30,23,25,31
NSOL21=9,NUMMAT=1,NDLS=1,MAXNOD=8,NOPSET=1,INTRS=4,INTT=3
NTP(1)=1
MASSDN(1)=3.89E-5
MATEV(1,1)=0.,3.0E7,3.0E7,3.0E7,.3,.3,.3
MATGA(1,1)=1.154E7,1.154E7,1.154E7
SDSLDI(1,5)=1
SDSLDF(1)=11.,11.,11.,11.
SSORLS(1)=1,2,3,4,5,6,7
SHELL1(1,2,3,4,5,6,7,8,9)=,,1,,1
SHELL2(2,4,5 9)=,,,,1
S1TO8(1)=44,45,46,25,50,51,52,47
S1TO8(2)=43,44,25,42,49,50,47,48
S1TO8(3)=31,54,45,44,56,57,51,50
S1TO8(4)=53,31,44,43,55,56,50,49
S1TO8(5)=58,41,31,53,59,60,56,55
S1TO8(6)=67,40,41,58,69,68,60,59
S1TO8(7)=70,39,40,67,72,71,68,69
S1TO8(8)=61,38,39,70,65,64,71,72
S1TO8(9)=62,37,38,61,66,63,64,65
```

Input Data - Static Uniform Pressure on One Side of Door (Concluded)

```
ELM(1)=1.,
'
8.
X(2000.)A()
Y(2000.)A()
Z(2000.)A()
X(2000.)Y(2000.)A()
X(2000.)Z(2000.)A()
Y(2000.)Z(2000.)A()
X(2000.)Z(2000.)Y(2000.)A()
X(2000.)Y(2000.)Z(2000.)AN()
X(2000.)Y(2000.)Z(2000.)AE()
X(2000.)Y(2000.)Z(2000.)ANE()
'
```

6.4.4 Input Data - Eigenvalue Calculation and Restart Creation (Continued)

```
HEADER=*EIGENVALUE SOLUTION OF A PROW-SHAPED DOOR/RESTART CREATION*
NUMNP=72,NELTYP=3,NP=24,NDYN=1
IX(1,13)=                                                              1,1,1,0,0,1,
IX(2,5,9,15,26,32,37)=                                                 1,0,0,0,0,1,
IX(3,6,12,16,25)=                                                      0,1,1,0,0,0,
IX(4,7,8,10,11,14,17 24,27 31,33 36,38 41,44)=                         0,0,0,0,0,0,
IX(42,46,47,52)=                                                       0,1,1,1,1,1,
IX(43,45,50,51,33,54,56 58,60,61,64,67,68,70,71)=                      0,0,0,1,1,1,
IX(48,49,55,59,65,69,72)=                                              0,0,1,1,1,1,
IX(62,63)=                                                             1,0,0,1,1,1,
IX(66)=                                                                1,0,1,1,1,1,
XYZT(1)=0.,0.,0.,0.,                  XYZT(2)=0.,0.,10.125
XYZT(3)=48.,0.,0.,0.,                 XYZT(4)=48.,0.,10.125
XYZT(5)=0.,0.,60.,0.,                 XYZT(6)=144.,
XYZT(7)=48.,0.,60.,0.,                XYZT(8)=144.,0.,10.125
XYZT(9)=0.,0.,110.,0.,                XYZT(10)=48.,0.,110.,
XYZT(11)=144.,0.,60.,0.,              XYZT(12)=250.94,
XYZT(13)=0.,0.,168.757,0.,            XYZT(14)=250.94,0.,10.125
XYZT(15)=0.,0.,206.,0.,               XYZT(16)=48.,0.,168.757
XYZT(17)=53.1,0.,164.8,0.,            XYZT(18)=106.2,0.,123.6,
XYZT(19)=123.728,0.,110.,0.,          XYZT(20)=144.,0.,94.271,
XYZT(21)=159.3,0.,82.4,0.,            XYZT(22)=188.1699,0.,60.,
XYZT(23)=212.4,0.,41.2,0.,            XYZT(24)=250.94,0.,11.297
XYZT(25)=265.5,0.,0.,0.,              XYZT(26)=0.,96.,206.,
XYZT(27)=53.15,96.,164.8,0.,          XYZT(28)=106.2,96.,123.6
XYZT(29)=159.3,96.,82.4,0.,           XYZT(30)=212.4,96.,41.2,
XYZT(31)=265.5,96.,0.,0.,             XYZT(32)=0.,178.5,103.,
XYZT(33)=53.1,162.,82.4,0.,           XYZT(34)=106.2,145.5,61.8,
XYZT(35)=159.32,129.,41.2,0.,         XYZT(36)=199.125,116.625,25.75
XYZT(37)=0.,261.,0.,0.,               XYZT(38)=53.1,228.,
XYZT(39)=106.2,195.,0.,0.,            XYZT(40)=159.3,162.,
XYZT(41)=212.4,129.,0.,0.,            XYZT(42)=321.,
XYZT(43)=317.42,47.82,0.,0.,          XYZT(44)=265.5,40.,
XYZT(45)=250.94,40.,0.,0.,            XYZT(46)=250.94
XYZT(47)=265.5,0.,-5.8,0.,            XYZT(48)=321.,0.,-5.8
XYZT(49)=317.42,47.82,-5.8,0.,        XYZT(50)=265.5,40.,-5.8
```

```
XYZT(51)=250.94,40.,-5.8,0.,          XYZT(52)=250.94,0.,-5.8
XYZT(53)=301.87,109.15,0.,0.,         XYZT(54)=238.95,112.5
XYZT(55)=301.87,109.15,-5.8,0.,       XYZT(56)=265.5,96.,-5.8
XYZT(57)=238.95,112.5,-5.8,0.,        XYZT(58)=274.36,166.63,
XYZT(59)=274.36,166.63,-5.8,0.,       XYZT(60)=212.4,129.63,-5.8,
XYZT(61)=72.81,312.63,0.,0.,          XYZT(62)=0.,321.,
XYZT(63)=0.,261.,-5.8,0.,             XYZT(64)=53.8,228.,-5.8
XYZT(65)=72.81,312.63,-5.8,0.,        XYZT(66)=0.,321.,-5.8
XYZT(67)=225.06,228.88,0.,0.,         XYZT(68)=159.3,162.,-5.8
XYZT(69)=225.06,228.88,-5.8,0.,       XYZT(70)=153.53,281.9,
XYZT(71)=106.2,195.,-5.8,0.,          XYZT(72)=153.53,281.9,-5.8
NBEAM=46,BNEPC=8,BNMPC=1
BMPC(1)=3.0E7,.3,7.36E-4,
BEPC(1)=11.7,,,284.,179.,179.
BEPC(2)=5.54,,,25.,54.2,3.8
BEPC(3)=2.51,,,.033,14.8,1.98
BEPC(4)=9.12,,,.534,110.,37.
BEPC(5)=9.16,,,141.97,88.1,88.1
BEPC(6)=7.35,,,0.463,53.3,17.1
BEPC(7)=0.01,,,1000.,1.,1.
BEPC(8)=0.01,,,1.,1.,1.
BEAM(1)=1,3,2,1,1
BEAM(2)=3,6,2,1,1,
BEAM(3)=6,12,2,1,1
BEAM(4)=12,25,2,1,1
BEAM(5)=24,25,2,1,5
BEAM(6)=23,24,2,1,5
BEAM(7)=22,23,2,1,5
BEAM(8)=21,22,2,1,5
BEAM(9)=20,21,2,1,5
BEAM(10)=19,20,2,1,5
BEAM(11)=18,19,2,1,5
BEAM(12)=17,18,2,1,5
BEAM(13)=16,17,2,1,5
BEAM(14)=15,16,2,1,5
BEAM(15)=2,4,1,1,2
BEAM(16)=4,8,1,1,2
```

Input Data - Eigenvalue Calculation and Restart Creation (Continued)

```
BEAM(17)=8,14,1,1,2
BEAM(18)=5,7,1,1,3
BEAM(19)=7,11,1,1,3
BEAM(20)=11,22,1,1,3
BEAM(21)=9,10,1,1,3
BEAM(22)=10,19,1,1,3
BEAM(23)=13,16,1,1,4
BEAM(24)=12,14,1,1,5
BEAM(25)=12,24,1,1,5
BEAM(26)=6,8,1,1,6
BEAM(27)=8,11,1,1,6
BEAM(28)=11,20,1,1,6
BEAM(29)=3,4,1,1,6
BEAM(30)=4,7,1,1,6
BEAM(31)=7,10,1,1,6
BEAM(32)=10,16,1,1,6
BEAM(33)=37,32,15,1,7
BEAM(34)=32,26,15,1,7
BEAM(35)=26,15,37,1,7
BEAM(36)=38,33,17,1,8
BEAM(37)=33,27,17,1,8
BEAM(38)=27,17,38,1,8
BEAM(39)=39,34,18,1,8
BEAM(40)=34,28,18,1,8
BEAM(41)=28,18,39,1,8
BEAM(42)=40,35,21,1,8
BEAM(43)=35,29,21,1,8
BEAM(44)=29,21,40,1,8
BEAM(45)=41,30,23,1,8
BEAM(46)=30,23,41,1,8
PMPI(1)=7.36E-4,,,,3.375E7,1.125E7,,3.375E7,,1.125E7
PELML=1.
NPLATE=14,PNDM=1
PLATE(1 14)=.875,-11.
IPLATE(1)=37,32,33,38
IPLATE(2)=32,26,27,33
IPLATE(3)=26,15,17,27
```

Input Data - Eigenvalue Calculation and Restart Creation (Concluded)

```
IPLATE(4)=38,33,34,39
IPLATE(5)=33,27,28,34
IPLATE(6)=27,17,18,28
IPLATE(7)=39,34,35,40
IPLATE(8)=34,28,29,35
IPLATE(9)=28,18,21,29
IPLATE(10)=40,35,36,41
IPLATE(11)=35,29,30,36
IPLATE(12)=29,21,23,30
IPLATE(13)=41,36,30,31
IPLATE(14)=30,23,25,31
NSOL21=9,NUMMAT=1,          MAXNOD=8,NOPSET=1,INTRS=4,INTT=3
NTP(1)=1
MASSDN(1)=3.89E-5
MATEV(1,1)=0.,3.0E7,3.0E7,3.0E7,.3,.3,.3
MATGA(1,1)=1.154E7,1.154E7,1.154E7
SSORLS(1)=1,2,3,4,5,6,7
SHELL1(1,2,3,4,5,6,7,8,9)=,,1,,1
SHELL2(2,4,5 9)=,,,,1
S1TO8(1)=44,45,46,25,50,51,52,47
S1TO8(2)=43,44,25,42,49,50,47,48
S1TO8(3)=31,54,45,44,56,57,51,50
S1TO8(4)=53,31,44,43,55,56,50,49
S1TO8(5)=58,41,31,53,59,60,56,55
S1TO8(6)=67,40,41,58,69,68,60,59
S1TO8(7)=70,39,40,67,72,71,68,69
S1TO8(8)=61,38,39,70,65,64,71,72
S1TO8(9)=62,37,38,61,66,63,64,65
```

6.4.5 Input Data - Dynamic Response Using Restart Tape

```
HEADER=*RESTART RESPONSE HISTORY ANALYSIS OF AN ARMOR DOOR*
  NUMNP=72,NELTYP=3,NF=24,NDYN=-2
NFN=1,NT=500,NOT=4,DT=.0001
NP(15,1)=1,,-10889.
NP(15,3)=1,,-14008.2
NP(17,1)=1,,-21778.
NP(17,3)=1,,-28016.5
NP(18,1)=1,,-21778.
NP(18,3)=1,,-28016.5
NP(21,1)=1,,-21778.
NP(21,3)=1,,-28016.5
NP(23,1)=1,,-21778.
NP(23,3)=1,,-28016.5
NP(25,1)=1,,-10889.
NP(25,3)=1,,-20379.8
NP(26,1)=1,,-19802.5
NP(26,2)=1,,-14351.5
NP(26,3)=1,,-25497.5
NP(27,1)=1,,-36790.1
NP(27,2)=1,,-24170.9
NP(27,3)=1,,-47366.5
NP(28,1)=1,,-31160.5
NP(28,2)=1,,-15109.6
NP(28,3)=1,,-40110.0
NP(29,1)=1,,-28655.
NP(29,2)=1,,-11072.6
NP(29,3)=1,,-36880.5
NP(30,1)=1,,-29299.3
NP(30,2)=1,,-12110.1
NP(30,3)=1,,-37711.
NP(31,1)=1,,-15755.4
NP(31,2)=1,,-7835.4
NP(31,3)=1,,-34739.5
NP(32,1)=1,,-17826.9
NP(32,2)=1,,-28703.0
NP(32,3)=1,,-22978.7
NP(33,1)=1,,-30023.8
NP(33,2)=1,,-48341.8
NP(33,3)=1,,-38701.
NP(34,1)=1,,-18765.2
NP(34,2)=1,,-30213.7
NP(34,3)=1,,-24188.1
NP(35,1)=1,,-13754.
NP(35,2)=1,,-22145.4
NP(35,3)=1,,-17728.9
NP(36,1)=1,,-10176.2
NP(36,2)=1,,-16384.7
NP(36,3)=1,,-13117.
```

Input Data - Dynamic Response Using Restart Tape (Concluded)

```
NP(37,1)=1,,-8913.5
NP(37,2)=1,,-14351.5
NP(37,3)=1,,-23129.9
NP(38,1)=1,,-15012.1
NP(38,2)=1,,-24170.9
NP(38,3)=1,,-49980.7
NP(39,1)=1,,-9382.6
NP(39,2)=1,,-15106.6
NP(39,3)=1,,-49139.
NP(40,1)=1,,-6877.
NP(40,2)=1,,-11072.6
NP(40,3)=1,,043077.4
NP(41,1)=1,,-7521.3
NP(41,2)=1,,-12110.1
NP(41,3)=1,-33541.5
NP(42,3)=1,,-6769.4
NP(43,3)=1,,-14565.9
NP(53,3)=1,,-15331.3
NP(58,3)=1,,-25884.4
NP(61,3)=1,,-33815.9
NP(62,3)=1,,-12724.7
NP(67,3)=1,,-38079.8
NP(70,3)=1,,-41483.3
NLP(1)=4,1.
T(1,1)=0.,T(1,2)=.001,T(1,3)=.0182,T(1,4)=1.
F(1,1)=0.,F(1,2)=1.,F(1,3)=0.,F(1,4)=0.
KKK=2,ISP=2
ICOMP(26,31,32,37,38)=1,2,3
KKKS=2,ISPS=2
IS(2,15)=1,2,3,4,5,6
IS(2,18)=1,2,3,4,5,6
IS(2,21)=1,2,3,4,5,6
IS(6,1)=1,2,3,4,5,6
IS(6,2)=1,2,3,4,5,6
IS(6,3)=1,2,3,4,5,6
IS(8,9)=7,8,9,10,11,12,13,14,15,16,17,18
```

6.4.6 Results

Static Analysis

Maximum deflection (at node 34)
u - -3.89 in
v = -6.23 in
ω = -5.11 in
Maximum axial force (in beam element 9)
$P_1 = 6.279 \times 10^4$ lb
Maximum bending moment (at node 20 in beam element 10)
$M_3 = 4.789 \times 10^5$ lb/in

One view of the armored door mesh is presented in Figure 80.

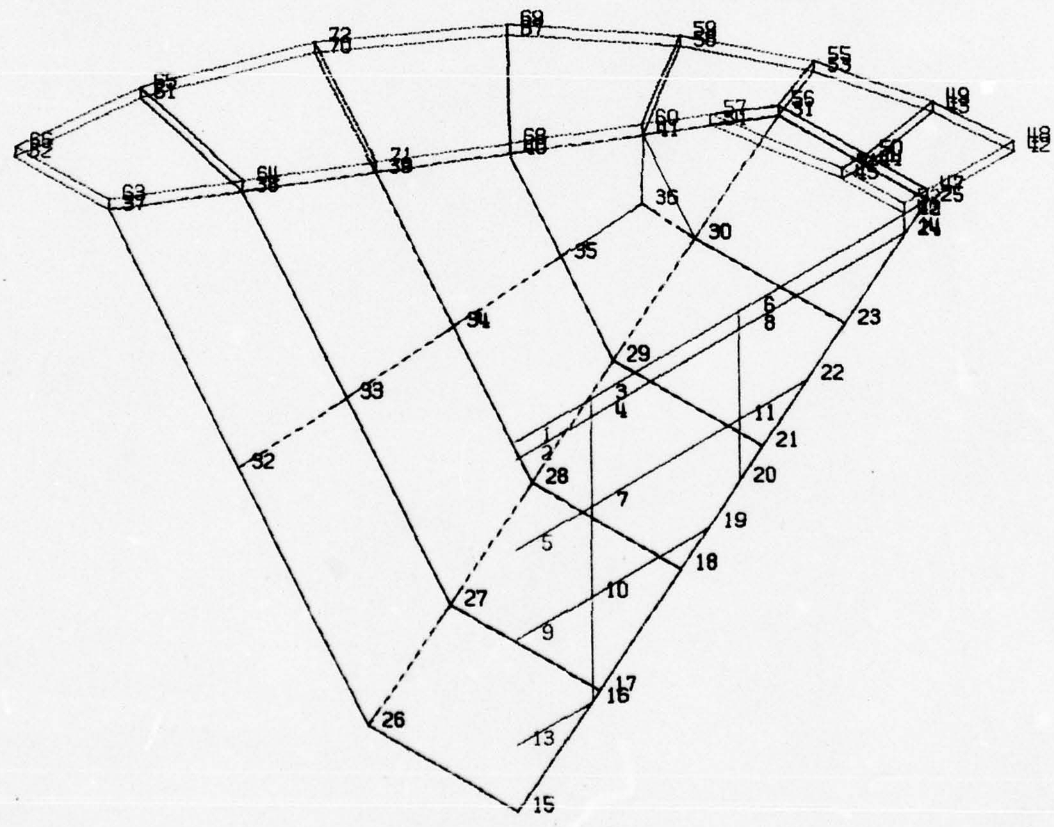


Figure 80. Mesh Plot of Armored Door - with Node Numbering

7. SUMMARY

These problems have served to provide some guidance with regard to the accuracy that may be expected with SAP IV. For example, the static response of beams and plates agrees quite well with classical theory with very few beam and plate elements respectively. Similarly, the use of a small number of thick shell elements with very large aspect ratios appeared to be adequate for thick plates, arches and shells.

For those cases where other analytical predictions or experimental data were available, the results of SAP IV were reasonably close when account is taken of the rather large elements, different boundary conditions and linear assumptions that were used throughout. There is no question that SAP IV can be extremely useful in assisting an engineer to optimize an aircraft shelter or shelter system design with respect to protection or cost. This latter conclusion is based on the analysis of the shelter and the prowed door that represent fairly complicated but realistic components of a shelter complex.

These problems have also illustrated the value of the free-format input program and the graphics package. For each problem, each input card contains nontrivial data that is easily constructed and understood. The flexibility of the plot package is indicated with the various views of the finite element models as well as with the time histories of several parameters that are significant to the engineer.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

The initial decision of choosing SAP IV appears to have been a good one. The problems associated with installing and using the program were much fewer than might be expected for a large code. Several problems with classical solutions were run to gain familiarity with the code and the numerical results were accurate. Furthermore, the solution routines, especially the modal technique for dynamic problems, were efficient and easy to use.

Although the basic code was quite satisfactory, it was evident that very little effort had been made to make the input and output data convenient for the user. The input data followed a rather rigid format with the requirement of blank spaces and blank cards very common and somewhat confusing at best. There was no method to check the input geometric data except by repeated scrutiny, which is not a very viable method especially for large problems. The output, in the form of printed data and plots from a printer, was cumbersome and rather unsuitable for the analysis of complicated structures. Furthermore, it was evident that the code had been constructed primarily with metal structures in mind, since there was no indication of property identification for concrete or reinforced concrete structures.

Since the primary objective of this study was a code that could be used in the dynamic analysis of concrete and reinforced concrete structures, it was necessary to derive a method for computing equivalent linear bending stiffnesses. For any realistic dynamic environment a given structural member will experience both positive and negative moments. Since many members used in aircraft shelter systems are not symmetrical with respect to positive and negative bending, it was necessary to extend an existing method to this case. The equivalent bending stiffness that was proposed was an average of the stiffnesses for the cracked and uncracked sections for both positive and negative bending. The results appear to be reasonable based on a limited amount of other analytical data.

The free-format input program that was developed simplifies the input of data for the average user. This program takes data in a simplified or free-format form and converts it to the format required by the SAP IV code. Thus, the user has the option of using the free-format form or of bypassing this program and submitting data in the SAP IV format. With the free-format input program, cards can be input in any order and only nonzero data is required. When certain data, such as boundary conditions are repetitive, or nodes are equally spaced, the program generates much of the data for the user. The result is that the free-format input consists of the minimal amount of data that is required for defining a problem. Not only

is this extremely convenient to the user, but the chance for error, such as a wrong number or a correct number in a wrong column, is significantly reduced.

Even with the free-format input there is still the possibility of errors in node or element definition that are extremely difficult to detect. The mesh plot program was devised to assist in this important aspect of data checking. Furthermore, a graphical display of elements can easily show elements that have a bad aspect ratio and can give a general indication concerning the degree of refinement that is almost impossible with printed data.

The mesh plot program has several options that were incorporated to assist the user. The viewing point is specified and can be changed from plot to plot. Some of the options that are available include the following:

1. A plot of all nodes and elements with labels

2. An unlabeled plot of all nodes and elements

3. Labeled or unlabeled plots of just the beam, plate or thick shell elements

4. Labeled or unlabeled plots of specified subsets of beam, plate or thick shell elements.

The regular output of SAP IV for dynamic problems consists of specified numerical data at each time step and printer plots of the same information. Neither of these forms is generally adequate for efficiently studying the response of a structure or for incorporating such data in a report. Thus, a time history program was constructed which maintained essentially the existing control parameters as those used for the printer plots, but which allowed the use of plotters that are usually available at any large computer installation.

A review of the output parameters for a typical dynamic analysis revealed that time history plots could be conveniently combined in groups of three. According to the particular element and node model, these groups were:

1. Displacements at a node

2. Rotations at a node

3. Bending moments and torque for a beam element

4. Shear resultants and axial force for a beam element

5. Membrane resultants for a thin plate element

6. Moment resultants for a thin plate element

7. Normal stress components for a thick shell element

8. Shear stress components for a thick shell element

Within any such group, one, two or all three histories can be requested. The largest absolute value of the requested functions over the specified time period is used as a normalizing factor and this factor together with identifying symbols are printed with each graph.

Although these additions to SAP IV have greatly enhanced its suitability for the analysis of aircraft shelter structures, there still remain several items which, if addressed successfully, could improve the usefulness of SAP IV even further. These are:

1. In dynamic problems, which use modal superposition, the generalized force vector is computed and stored in core for all time steps prior to the integration of the modal equations. Consequently, the core requirements of a problem can vary quite significantly depending upon the number of time steps requested for solution and can, on occasion, cause a problem to exceed storage limits. It appears that this difficulty can be corrected by an alteration to SAP IV in which the generalized forcing function vectors are computed and stored outside of core to be accessed when needed. The required vectors can then be brought into core either sequentially or in blocks as the nodal integration proceeds.

2. Inclusion of a capability of calculating and plotting of principal stresses, strains and directions. This feature would be very helpful in determining the possibility of failure.

3. Additional graphical display showing both deformed and undeformed states of the structure.

4. Inclusion of advanced band with minimization techniques which would decrease the computer time necessary for a particular problem.

5. Resolving the limitiation of a maximum of eight displacement components for output plotting.

APPENDIX A

FREE FORMAT INPUT PROGRAM

The Free Format Input Program (FFIP) produces an input data file acceptable to the SAP IV program through extremely flexible input instructions and is available for three element types - beam, thin plate, and thick shell (21 nodes).

The two basic parts in FFIP are key words and entries. These two parts are always linked with an equal sign. A key word must appear before an equal sign, and the entry must appear to the right of the equal sign. Key words may be nonsubscripted, single subscripted, or multiple subscripted. For each single subscripted and multiple subscripted key word, a set of parentheses must be included before an equal sign. The entries may be single or multiple and may be in floating point, fixed point, or alpha-numeric. This information is specifically stated for each key word. Variables, values or strings of characters may be placed anywhere on a card as long as three elements are intact in the following order: key word, equal sign, and entry. More than one key word can be placed on one card, again, as long as a set of three elements as described earlier remains intact and is separated from another set by a comma or a blank. Furthermore, when two or more key words are punched on one card, the number of entries required for a previous key word must be completely satisfied. All key words listed in this appendix are recognized by FFIP, and any misspelled key words will not be recognized. Diagnostic error messages will be printed for misspelled key words, and the job will be aborted.

Further requirements for input include:

- There must not be any blanks within an exponential field.

- An integer or floating point number may be terminated by a comma.

  Consecutive commas may be used to indicate missing fields, but care should be taken:

  7,,b̸5 means the second number is missing (default=0) but

  7b̸,,b̸5 means the second and third numbers are missing.

- A'+' in column 80 causes the next line to be read and the free format scan continues. (Usage of this feature should be spared to preserve the flexibility of the data deck.)

FFIP KEY WORDS AND ENTRIES

Explanations:

Keyword and type of allocation	-	key word and type of allocation which may be NS, SS or MS where: NS - nonscripted SS - single subscripted MS - multiple subscripted
No. of entry	-	number of values to be entered to the right of the equal sign
Type of entry	-	self-explanatory
Usage	-	the first line is reserved for description or usage. Another line denoted by two dashes gives an example of how input should appear on card.
Ref.	-	more specific information on usage is referenced to the SAP IV manual by section and page number.

KEYWORD AND TYPE OF ALLOCATION		NO. OF ENTRY	TYPE OF ENTRY	USAGE	REF.
ALPHA	NS	1	REAL	DAMPING FACTOR FOR A FORCED DYNAMIC RESPONSE ANALYSIS --ALPHA=ENTRY	VII.8
AT	SS	1	REAL	ARRIVAL TIME --AT(E1)=E2 WHERE E1=ARRIVAL TIME NUMBER (INTEGER) .LE. NAT E2=ENTRY	VII.12
BEAM	SS	12	INTEGER	BEAM DATA --BEAM(E1)=E2,E3,E4,E5,E6,E7,E8,E9,E10,E11, E12,E13 WHERE E1=BEAM ELEMENT NUMBER .LE. NBEAM E2=NODE NUMBER I E3=NODE NUMBER J E4=NODE NUMBER K E5=MATERIAL PROPERTY NUMBER E6=ELEMENT PROPERTY NUMBER E7=FIXED END FORCE ID FOR ELEMENT LOAD CASE A E8=FIXED END FORCE ID FOR ELEMENT LOAD CASE B E9=FIXED END FORCE ID FOR ELEMENT LOAD CASE C E10=FIXED END FORCE ID FOR ELEMENT LOAD CASE D E11=END RELEASE CODE AT NODE I E12=END RELEASE CODE AT NODE J E13=OPTIONAL PARAMETER K FOR AUTOMATIC GENERATION	IV.2.3
BELFX	NS	4	REAL	ELEMENT LOAD FACTOR - MULTIPLIER OF GRAVITY LOAD IN THE +X DIRECTION --BELFX=E1,E2,E3,E4 WHERE E1=ELEMENT LOAD CASE A E2=ELEMENT LOAD CASE B E3=ELEMENT LOAD CASE C E4=ELEMENT LOAD CASE D	IV.2.2
BELFY	NS	4	REAL	ELEMENT LOAD FACTOR - MULTIPLIER OF GRAVITY LOAD IN THE +Y DIRECTION --BELFY=E1,E2,E3,E4 WHERE E1=ELEMENT LOAD CASE A E2=ELEMENT LOAD CASE B E3=ELEMENT LOAD CASE C E4=ELEMENT LOAD CASE D	IV.2.2
BELFZ	NS	4	REAL	ELEMENT LOAD FACTOR - MULTIPLIER OF GRAVITY LOAD IN THE +Z DIRECTION --BELFZ=E2,E2,E3,E4 WHERE E1=ELEMENT LOAD CASE A E2=ELEMENT LOAD CASE B E3=ELEMENT LOAD CASE C E4=ELEMENT LOAD CASE D	IV.2.2

```
KEYWORD AND    NO.  TYPE  .  USAGE                                          . REF.
  TYPE OF      OF    OF   .                                                 .
  ALLOCATION ENTRY ENTRY  .                                                 .
--------------------------.-------------------------------------------------.--------
BEPC      SS     6   REAL .BEAM ELEMENT PROPERTY                            .IV.2.1
                          .--BEPC(E1)=E2,E3,E4,E5,E6,E7                     .
                          .  WHERE                                          .
                          .     E1=GEOMETRIC PROPERTY NUMBER (INTEGER)      .
                          .        .LE. BNEPC                               .
                          .     E2=AXIAL AREA                               .
                          .     E3=SHEAR AREA ASSOCIATED WITH SHEAR         .
                          .        FORCES IN LOCAL 2-DIRECTION              .
                          .     E4=SHEAR AREA ASSOCIATED WITH SHEAR         .
                          .        FORCES IN LOCAL 3-DIRECTION              .
                          .     E5=TORSIONAL INERTIA                        .
                          .     E6=FLEXURAL INERTIA ABOUT LOCAL 2-AXIS      .
                          .     E7=FLEXURAL INERTIA ABOUT LOCAL 3-AXIS      .
BETA      NS     1   REAL .DAMPING FACTOR FOR A FORCED DYNAMIC              .VII.8
                          .RESPONSE ANALYSIS                                .
                          .--BETA=ENTRY                                     .
BFEFI     SS     6   REAL .BEAM FIXED END FORCES                            .IV.2.2
                          .--BFEFI(E1)=E2,E3,E4,E5,E6,E7                    .
                          .  WHERE                                          .
                          .     E1=FIXED-END FORCE NUMBER (INTEGER)         .
                          .        .LE. BNFEF3                              .
                          .     E2=FIXED-END FORCE IN LOCAL 1-DIRECTION     .
                          .        AT NODE I                                .
                          .     E3=FIXED-END FORCE IN LOCAL 2-DIRECTION     .
                          .        AT NODE I                                .
                          .     E4=FIXED-END FORCE IN LOCAL 3-DIRECTION     .
                          .        AT NODE I                                .
                          .     E5=FIXED END MOMENT ABOUT LOCAL             .
                          .        1-DIRECTION AT NODE I                    .
                          .     E6=FIXED END MOMENT ABOUT LOCAL             .
                          .        2-DIRECTION AT NODE I                    .
                          .     E7=FIXED END MOMENT ABOUT LOCAL             .
                          .        3-DIRECTION AT NODE I                    .
BFEFJ     SS     6   REAL .BEAM FIXED END FORCES                            .IV.2.3
                          .--BFEFJ(E1)=E2,E3,E4,E5,E6,E7                    .
                          .  WHERE                                          .
                          .     E1=FIXED-END FORCE NUMBER (INTEGER)         .
                          .        .LE. BNFEF3                              .
                          .     E2=FIXED-END FORCE IN LOCAL 1-DIRECTION     .
                          .        AT NODE J                                .
                          .     E3=FIXED-END FORCE IN LOCAL 2-DIRECTION     .
                          .        AT NODE J                                .
                          .     E4=FIXED-END FORCE IN LOCAL 3-DIRECTION     .
                          .        AT NODE J                                .
                          .     E5=FIXED-END MOMENT ABOUT LOCAL             .
                          .        1-DIRECTION AT NODE J                    .
                          .     E6=FIXED-END MOMENT ABOUT LOCAL             .
                          .        2-DIRECTION AT NODE J                    .
                          .     E7=FIXED-END MOMENT ABOUT LOCAL             .
                          .        3-DIRECTION AT NODE J                    .
```

KEYWORD AND TYPE OF ALLOCATION		NO. OF ENTRY	TYPE OF ENTRY	USAGE	REF.
BMPC	SS	4	REAL	BEAM MATERIAL PROPERTY --BMPC(E1)=E2,E3,E4,E5 WHERE E1=MATERIAL ID NUMBER (INTEGER) .LE. BNMPC E2=YOUNG'S MODULUS E3=POISSON'S RATIO E4=MASS DENSITY E5=WEIGTH DENSTIT	IV.2.1
BNEPC	NS	1	INTEGER	NUMBER OF BEAM ELEMENT PROPERTY SETS --BNEPC=ENTRY	IV.2.1
BNFEFS	NS	1	INTEGER	NUMBER OF FIXED END FORCE SETS --BNFEFS=ENTRY	IV.2.1
BNMPC	NS	1	INTEGER	NUMBER OF BEAM MATERIAL PROPERTY SETS --BNMPC=ENTRY	IV.2.1
CLMD	MS	6	REAL	CONCENTRATED LOAD/MASS DATA --CLMD(E1,E2)=E3,E4,E5,E6,E7,E8 WHERE E1=NODAL POINT NUMBER (INTEGER) .LE. NUMNP E2=STRUCTURE LOAD CASE NUMBER (INTEGER) .LE. LL GE.1, STATIC ANALYSIS EQ.0, DYNAMIC ANALYSIS E3=X-DIRECTION FORCE OR TRANSLATIONAL MASS COEFFICIENT E4=Y-DIRECTION FORCE OR TRANSLATIONAL MASS COEFFICIENT E5=Z-DIRECTION FORCE OR TRANLSATIONAL MASS COEFFICIENT E6=X-AXIS MOMENT OR ROTATIONAL INERTIA E7=Y-AXIS MOMENT OR ROTATIONAL INERTIA E8=Z-AXIS MOMENT OR ROTATIONAL INERTIA	V.1
COFQ	NS	1	REAL	CUT-OFF FREQUENCY --COFQ=ENTRY	VII.3
CT	SS	1	ALPHA	SYMBOL DESCRIBING COORDINATE SYSTEM FOR THIS NODE EQ. (BLANK) CARTESIAN (X,Y,Z) EQ.C, CYLINDRICAL (R,Y,THETA) --CT(E1)=E2 WHERE E1=NODAL POINT NUMBER (INTEGER) .LE. NUMNP E2=ENTRY	III.1
DAMP	NS	1	REAL	DAMPING FACTOR (NDYN=2) --DAMP=ENTRY	VII.8
DT	NS	1	REAL	SOLUTION TIME STEP --DT=ENTRY	VII.8
ELM	SS	4	REAL	ELEMENT LOAD MULTIPLIERS --ELM(E1)=E2,E3,E4,E5 WHERE E1=LOAD CASE NUMBER (INTEGER) LE. LL E2=MULTIPLIER FOR ELEMENT LOAD CASE A E3=MULTIPLIER FOR ELEMENT LOAD CASE B E4=MULTIPLIER FOR ELEMENT LOAD CASE C E5=MULTIPLIER FOR ELEMENT LOAD CASE D	VI.1

KEYWORD AND	TYPE OF ALLOCATION	NO. OF ENTRY	TYPE OF ENTRY	USAGE	REF.
F	MS	1	REAL	TIME FUNCTION DEFINITION FOR RESPONSE	VII.14
				HISTORY ANALYSIS	
				--F(E1,E2)=E3	
				WHERE	
				E1=TIME FUNCTION NUMBER (INTEGER)	
				.LE. NFN	
				E2=DEFINITION POINT NUMBER (INTEGER)	
				.LE. NLP(NFN)	
				E3=FUNCTION VALUE	
FX	NS	1	REAL	FACTOR FOR X-DIRECTION INPUT FOR	VII.23
				RESPONSE SPECTRUM ANALYSIS	
				--FX=ENTRY	
FY	NS	1	REAL	FACTOR FOR Y-DIRECTION INPUT FOR	VII.23
				RESPONSE SPECTRUM ANALYSIS	
				--FY=ENTRY	
FZ	NS	1	REAL	FACTOR FOR Z-DIRECTION INPUT FOR	VII.23
				RESPONSE SPECTRUM ANALYSIS	
				--FZ=ENTRY	
HEADER	NS	6	ALPHA	HEADING INFORMATION	I.1
				--HEADER=*58CHARACTERS INCLUDING BLANK*	
HED	SS	6	ALPHA	LABEL INFORMATION FOR RESPONSE HISTORY	VII.15
				ANALYSIS	
				--HED(E1)=*E2*	
				WHERE	
				E1=FUNCTIONAL DEFINNITION POINT NUMBER	
				(INTEGER) .LE.NFN	
				E2=58 CHARACTERS INCLUDING BLANK	
HEDSP	NS	6	ALPHA	HEADING INFORMATION USED TO LABEL THE	VII.24
				SPECTRUM TABLE	
				--HEDSP=*58 CHARACTERS INCLUDING BLANK*	
ICOMP	MS	6	INTEGER	DISPLACEMENT OUTPUT DATA	VII.16
				--ICOMP(E1)=E2,E3,E4,E5,E6,E7	
				WHERE	
				E1=NODAL POINT NUMBER (INTEGER)	
				.LE. NUMNP	
				E2=DISPLACEMENT COMPONENT, REQUEST 1	
				E3=DISPLACEMENT COMPONENT, REQUEST 2	
				E4=DISPLACEMENT COMPONENT, REQUEST 3	
				E5=DISPLACEMENT COMPONENT, REQUEST 4	
				E6=DISPLACEMENT COMPONENT, REQUEST 5	
				E7=DISPLACEMENT COMPONENT, REQUEST 6	
IFPR	NS	1	INTEGER	FLAG FOR PRINTING INTERMEDIATE MATRICES	VII.3
				--IFPR=ENTRY	
IFSS	NS	1	INTEGER	FLAG FOR PERFORMING THE STURM SEQUENCE CHECK	VII.3
				--IFSS=ENTRY	
INTRS	NS	1	INTEGER	STANDARD INTEGRATION ORDER FOR THE NATURAL	IV.8.5
				(R,S) DIRECTIONS	
				--INTRS=ENTRY	
INTT	NS	1	INTEGER	STANDARD INTEGRATION ORDER FOR THE NATURAL	IV.8.5
				(T)-DIRECTION	
				--INTT=ENTRY	

KEYWORD AND TYPE OF ALLOCATION		NO. OF ENTRY	TYPE OF ENTRY	USAGE	REF.
IPLATE	SS	7	INTEGER	PLATE DATA --IPLATE(E1)=E2,E3,E4,E5,E6,E7,E8 WHERE E1=PLATE ELEMENT NUMBER .LE. NPLATE E2=NODE I E3=NODE J E4=NODE K E5=NODE L E6=NODE O E7=MATERIAL IDENTIFICATION NUMBER E8=ELEMENT DATA GENERATOR	IV.6.2
IS	MS	12	INTEGER	ELEMENT STRESS COMPONENT OUTPUT --IS(E1,E2)=E3,E4,E5,E6,E7,E8,E9,E10,E11,E12, E13,E14 WHERE E1=ELEMENT TYPE E2=ELEMENT NUMBER .LE. NBEAM, IF E1=2 .LE. NPLATE, IF E1=6 .LE. NSOL21, IF E1=8 E3=STRESS COMPONENT NUMBER, REQUEST 1 E4=STRESS COMPONENT NUMBER, REQUEST 2 E5=STRESS COMPONENT NUMBER, REQUEST 3 E6=STRESS COMPONENT NUMBER, REQUEST 4 E7=STRESS COMPONENT NUMBER, REQUEST 5 E8=STRESS COMPONENT NUMBER, REQUEST 6 E9=STRESS COMPONENT NUMBER, REQUEST 7 E10=STRESS COMPONENT NUMBER, REQUEST 8 E11=STRESS COMPONENT NUMBER, REQUEST 9 E12=STRESS COMPONENT NUMBER, REQUEST 10 E13=STRESS COMPONENT NUMBER, REQUEST 11 E14=STRESS COMPONENT NUMBER, REQUEST 12	VII.17
ISP	NS	1	INTEGER	PLOT SPACING INDICATOR FOR DISPLACEMENT OUTPUT --ISP=ENTRY	VII.15
ISPS	NS	1	INTEGER	PLOT SPACING INDICATOR FOR STRESS OUTPUT --ISPS=ENTRY	VII.17
IST	NS	1	INTEGER	INPUT SPECTRUM TYPE --IST=ENTRY	VII.25
IX	SS	6	INTEGER	BOUNDARY CONDITION DATA --IX(E1)=E2,E3,E4,E5,E6,E7 WHERE E1=NODAL POINT NUMBER .LE. NUMNP E2=X-TRANSLATION BOUNDARY CONDITION CODE. E3=Y-TRANSLATION BOUNDARY CONDITION CODE. E4=Z-TRANSLATION BOUNDARY CONDITION CODE. E5=X-ROTATION BOUNDARY CONDITION CODE E6=Y-ROTATION BOUNDARY CONDITION CODE E7=Z-ROTATION BOUNDARY CONDITION CODE	III.1
KEQB	NS	1	INTEGER	NUMBER OF DEGREES OF FREEDOM (EQUATION) PER BLOCK OF STORAGE --KEQB=ENTRY	II.1
KKK	NS	1	INTEGER	OUTPUT TYPE INDICATOR (DISPLACEMENT) .EQ.1. PRINT HISTORIES AND MAXIMA .EQ.2. PRINTER PLOT HISTORIES AND RECOVERY OF MAXIMA .EQ.3. RECOVERY OF MAXIMA ONLY --KKK=ENTRY	VII.15

KEYWORD AND TYPE OF ALLOCATION		NO. OF ENTRY	TYPE OF ENTRY	USAGE	REF.
KKKS	NS	1	INTEGER	OUTPUT TYPE INDICATOR (STRESS) EQ.1. PRINT HISTORIES AND MAXIMA EQ.2. PRINTER PLOT HISTORIES AND RECOVERY OF MAXIMA EQ.3. RECOVERY OF MAXIMA ONLY	VII.17
LL	NS	1	INTEGER	NUMBER OF STRUCTURAL LOAD CASES --LL=ENTRY	II.1
MASSON	SS	1	REAL	MASS DENSITY OF THE MATERIAL USED TO COMPUTE THE MASS MATRIX IN A DYNAMIC ANALYSIS --MASSON(E1)=E2 WHERE E1=MATERIAL IDENTIFICATION NUMBER (INTEGER) .LE. NUMMAT E2=ENTRY	IV.8.6
MATDES	SS	4	ALPHA	SHELL MATERIAL DESCRIPTION --MATDES(E1)=*E2* WHERE E1=MATERIAL IDENTIFICATION NUMBER (INTEGER) .LE. NUMMAT E2=38 CHARACTERS INCLUDING BLANKS	IV.8.6
MATEV	MS	7	REAL	SHELL MATERIAL PROPERTY DATA --MATEV(E1,E2)=E3,E4,E5,E6,E7,E8,E9 WHERE E1=MATERIAL IDENTIFICATION NUMBER .LE.NUMMAT E2=TEMPERATURE NUMBER (INTEGER) .LE. NTP(NUMMAT) E3=TEMPERATURE E4=ORTHOTROPIC ELASTIC MODULO (E11) E5=ORTHOTROPIC ELASTIC MODULO (E22) E6=ORTHOTROPIC ELASTIC MODULO (E33) E7=POISSON'S RATIO E8=POISSON'S RATIO E9=POISSON'S RATIO	IV.8.7
MATGA	MS	6	REAL	SHELL MATERIAL PROPERTY DATA --MATGA(E1,E2)=E3,E4,E5,E6,E7,E8 WHERE E1=MATERIAL IDENTIFICATION NUMBER (INTEGER) .LE. NUMMAT E2=TEMPERATURE NUMBER (INTEGER) .LE. NTP(NUMMAT) E3=SHEAR MODULO (G12) E4=SHEAR MODULO (G13) E5=SHEAR MODULO (G23) E6=COEFFICIENT OF THERMAL EXPANSION E7=COEFFICIENT OF THERMAL EXPANSION E8=COEFFICIENT OF THERMAL EXPANSION	IV.8.7
MAXNOD	NS	1	INTEGER	SHELL MAXIMUM NUMBER OF NODES USED TO DESCRIBES ANY ONE ELEMENT --MAXNOD=ENTRY	IV.8.1
MAXTP	NS	1	INTEGER	SHELL MAXIMUM NUMBER OF TEMPERATURE POINTS USED IN THE TABLE FOR ANY MATERIAL --MAXTP=ENTRY	IV.8.1
MODEX	NS	1	INTEGER	PROGRAM EXECUTION MODE --MODEX=ENTRY	II.1

KEYWORD AND TYPE OF ALLOCATION		NO. OF ENTRY	TYPE OF ENTRY	USAGE	REF.
NAD	NS	1	INTEGER	TOTAL NUMBER OF VECTORS TO BE USED IN A SUBSPACE ITERATION SOLUTION FOR EIGENVALUES/ VECTORS --NAD=ENTRY	II.1
NAT	NS	1	INTEGER	NUMBER OF DIFFERENT ARRIVAL TIMES FOR THE FORCING FUNCTIONS --NAT=ENTRY	VII.8
NATX	NS	1	INTEGER	GROUND MOTION CONTROL DATA - ARRIVAL TIME NUMBER, X-DIRECTION --NATX=ENTRY	VII.11
NATY	NS	1	INTEGER	GROUND MOTION CONTROL DATA - ARRIVAL TIME NUMBER, Y-DIRECTION --NATY=ENTRY	VII.11
NATZ	NS	1	INTEGER	GROUND MOTION CONTROL DATA - ARRIVAL TIME NUMBER, Z-DIRECTION --NATZ=ENTRY	VII.11
NBEAM	NS	1	INTEGER	NUMBER OF BEAM ELEMENT --NBEAM=ENTRY	IV.2.1
NDLS	NS	1	INTEGER	NUMBER OF DIFFERENT DISTRIBUTED LOAD --NDLS=ENTRY	IV.8.1
NDYN	NS	1	INTEGER	ANALYSIS TYPE CODE --NDYN=ENTRY	II.1
NELTYP	NS	1	INTEGER	NUMBER OF ELEMENT GROUPS --NELTYP=ENTRY	II.1
NF	NS	1	INTEGER	NUMBER OF FREQUENCIES TO BE FOUND IN THE EIGENVALUE SOLUTION --NF=ENTRY	II.1
NFN	NS	1	INTEGER	NUMBER OF DIFFERENT TIME FUNCTIONS --NFN=ENTRY	VII.7
NFNX	NS	1	INTEGER	GROUND MOTION CONTROL DATA - TIME FUNCTION NUMBER DESCRIBING THE GROUND ACCELERATION IN THE X-DIRECTION --NFNX=ENTRY	VII.11
NFNY	NS	1	INTEGER	GROUND MOTION CONTROL DATA - TIME FUNCTION NUMBER DESCRIBING THE GROUND ACCELERATION IN THE Y-DIRECTION --NFNY=ENTRY	VII.11
NFNZ	NS	1	INTEGER	GROUND MOTION CONTROL DATA - TIME FUNCTION NUMBER DESCRIBING THE GROUND ACCELERATION IN THE Z-DIRECTION	VII.11
NFO	NS	1	INTEGER	NUMBER OF STARTING ITERATION VECTORS TO BE READ FROM TAPE 10 --NFO=ENTRY	VII.3
NGM	NS	1	INTEGER	GROUND MOTION INDICATOR --NGM=ENTRY	VII.8
NITEM	NS	1	INTEGER	MAXIMUM NUMBER OF ITERATIONS ALLOWED TO REACH THE CONVERGENCE TOLERANCE --NITEM=ENTRY	VII.3
NLP	SS	2	INTEGER	NUMBER OF FUNCTION DEFINITION POINTS --NLP(E1)=E2,E3 WHERE E1=TIME FUNCTION NUMBER .LE. NFN E2=NUMBER OF FUNCTION DEFINITION POINTS E3=SCALE FACTOR TO BE APPLIED TO F(T) VALUES	VII.13

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KEYWORD AND     NO.   TYPE  .  USAGE                                         . REF.
  TYPE OF       OF    OF    .                                                .
  ALLOCATION ENTRY ENTRY    .                                                .
----------------------------.------------------------------------------------.--------
NOPSET     NS    1   INTEGER.SHELL NUMBER OF SETS OF DATA REQUESTING         .IV.8.1
                            .STRESS OUTPUT AT VARIOUS ELEMENT LOCATIONS      .
                            .--NOPSET=ENTRY                                  .
NORTHO     NS    1   INTEGER.SHELL NUMBER OF DIFFERENT SETS OF MATERIAL      .IV.8.1
                            .AXIS ORIENTATION DATA                           .
                            .--NORTHO=ENTRY                                  .
NOT        NS    1   INTEGER.OUTPUT PRINT INTERVAL FOR STRESSES,             .VII.8
                            .DISPLACEMENTS                                   .
                            .--NOT=ENTRY                                     .
NP         MS    3   MIXED  .TIME-VARYING LOAD DATA                          .VII.10
                            .--NP(E1,E2)=E3,E4,E5                            .
                            .  WHERE                                         .
                            .    E1=NODAL POINT WHERE THE LOAD               .
                            .       COMPONENT (FORCE OR MOMENT) IS           .
                            .       APPLIED (INTEGER) .LE. NUMNP             .
                            .    E2=DEGREE OF FREEDOM (INTEGER)              .
                            .       .GE. 1 .AND. .LE. 6                      .
                            .    E3=TIME FUNCTION NUMBER (INTEGER)           .
                            .       .LE. NFN                                 .
                            .    E4=ARRIVAL TIME NUMBER (INTEGER)            .
                            .    E5=SCALAR MULTIPLIER FOR THE                .
                            .       TIME FUNCTION (REAL)                     .
NPLATE     NS    1   INTEGER.NUMBER OF PLATE ELEMENT                         .IV.6.1
                            .--NPLATE=ENTRY                                  .
NPTS       NS    1   INTEGER.NUMBER OF DEFINITION POINTS IN THE SPECTRUM     .VII.24
                            .TABLE                                           .
                            .--NPTS=ENTRY                                    .
NSOL21     NS    1   INTEGER.NUMBER OF SHELL ELEMENTS                        .IV.8.1
                            .--NSOL21=ENTRY                                  .
NT         NS    1   INTEGER.TOTAL NUMBER OF SOLUTION TIME SREPS             .VII.8
                            .--NT=ENTRY                                      .
NTP        SS    1   INTEGER.NUMBER OF DIFFERENT TEMPERATURES AT             .IV.8.6
                            .WHICH PROPERTIES ARE GIVEN                      .
                            .--NTP(E1)=E2                                    .
                            .  WHERE                                         .
                            .    E1=MATERIAL IDENTIFICATION NUMBER           .
                            .       (INTEGER)  .LE. NUMMAT                   .
                            .    E2=NUMBER OF DIFFERENT TEMPERATURES         .
                            .       .LE. MAXTP                               .
NUMMAT     NS    1   INTEGER.NUMBER OF DIFFERENT MATERIALS (SHELL)           .IV.8.1
                            .--NUMMAT=ENTRY                                  .
NUMNP      NS    1   INTEGER.NUMBER OF NODAL POINTS                          .II.1
                            .--NUMNP=ENTRY                                   .
PELML      NS    4   REAL   .PLATE ELEMENT LOAD MULTIPLIER                   .IV.6.1
                            .--PELML=E1,E2,E3,E4                             .
                            .  WHERE                                         .
                            .    E1=DISTRIBUTED LATERAL LOAD MULTIPLIER      .
                            .       FOR LOAD CASE A                          .
                            .    E2=DISTRIBUTED LATERAL LOAD MULTIPLIER      .
                            .       FOR LOAD CASE B                          .
                            .    E3=DISTRIBUTED LATERAL LOAD MULTIPLIER      .
                            .       FOR LOAD CASE C                          .
                            .    E4=DISTRIBUTED LATERAL LOAD MULTIPLIER      .
                            .       FOR LOAD CASE D                          .
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KEYWORD AND TYPE OF ALLOCATION		NO. OF ENTRY	TYPE OF ENTRY	USAGE	REF.
PELMT	NS	4	REAL	PLATE ELEMENT LOAD MULTIPLIER --PELMT=E1,E2,E3,E4 WHERE E2=TEMERATURE MULTIPLIER FOR LOAD CASE B E3=TEMERATURE MULTIPLIER FOR LOAD CASE C E4=TEMERATURE MULTIPLIER FOR LOAD CASE D	IV.6.1
PELMX	NS	4	REAL	PLATE ELEMENT LOAD MULTIPLIER --PELMX=E1,E2,E3,E4 WHERE E1=X-DIRECTION ACCELERATION FOR LOAD CASE A E2=X-DIRECTION ACCELERATION FOR LOAD CASE B E3=X-DIRECTION ACCELERATION FOR LOAD CASE C E4=X-DIRECTION ACCELERATION FOR LOAD CASE D	IV.6.1
PELMY	NS	4	REAL	PLATE ELEMENT LOAD MULTIPLIER --PELMY=E1,E2,E3,E4 WHERE E1=Y-DIRECTION ACCELERATION FOR LOAD CASE A E2=Y-DIRECTION ACCELERATION FOR LOAD CASE B E3=Y-DIRECTION ACCELERATION FOR LOAD CASE C E4=Y-DIRECTION ACCELERATION FOR LOAD CASE D	IV.6.1
PELMZ	NS	4	REAL	PLATE ELEMENT LOAD MULTIPLIER --PELMZ=E1,E2,E3,E4 WHERE E1=Z-DIRECTION ACCELERATION FOR LOAD CASE A E2=Z-DIRECTION ACCELERATION FOR LOAD CASE B E3=Z-DIRECTION ACCELERATION FOR LOAD CASE C E4=Z-DIRECTION ACCELERATION FOR LOAD CASE D	IV.6.1
PLATE	SS	4	REAL	PLATE DATA --PLATE(E1)=E2,E3,E4,E5 WHERE E1=PLATE ELEMENT NUNBER (INTEGER) .LE.NPLATE E2=ELEMENT THICKNESS E3=DISTRIBUTED LATERAL LOAD E4=MEAN TEMPERATURE VARIATION T FROM THE REFERENCE LEVEL) UNDEFORMED POSITIO E5=MEAN TEMPERATURE GRADIENT ACROSS THE SHELL THICKNESS	IV.6.2

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KEYWORD AND      NO.  TYPE  .  USAGE                                            . REF.
  TYPE OF        OF    OF   .                                                   .
  ALLOCATION ENTRY ENTRY    .                                                   .
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PMPI       SS     10  REAL  .PLATE MATERIAL PROPERTY INFORMATION                .IV.6.1
                            .--PMPI(E1)=E2,E3,E4,E5,E6,E7,E8,E9,E10,E11         .
                            .  WHERE                                            .
                            .    E1=MATERIAL IDENTIFICATION NUMBER              .
                            .       (INTEGER) .LE. PNOM                         .
                            .    E2=MASS DENSITY                                .
                            .    E3=THERMAL EXPANSION COEFFICIENT (X)           .
                            .    E4=THERMAL EXPANSION COEFFICIENT (Y)           .
                            .    E5=THERMAL EXPANSION COEFFICIENT (Z)           .
                            .    E6=ELASTICITY ELEMNT CXX                       .
                            .    E7=ELASTICITY ELEMNT CXY                       .
                            .    E8=ELASTICITY ELEMNT CXS                       .
                            .    E9=ELASTICITY ELEMNT CYY                       .
                            .    E10=ELASTICITY ELEMENT CYS                     .
                            .    E11=ELASTICITY ELEMENT CXY                     .
PNOM       NS     1   INTEGER.NUMBER OF PLATE MATERIAL PROPERTY SET             .IV.6.1
                            .--PNOM=ENTRY                                       .
ROTL       NS     1   REAL  .CONVERGENCE TOLERANCE FOR THE HIGHEST              .VII.3
                            .REQUESTED EIGENVALUE                               .
                            .--ROTL=ENTRY                                       .
SDSLDF     SS     7   REAL  .DISTRIBUTED SURFACE LOAD DATA                      .IV.8.9
                            .IF LT .EQ. 1                                       .
                            .--SDSLDF(E1)=E2,E3,E4,E5                           .
                            .  WHERE                                            .
                            .    E1=LOAD SET ID NUMBER (INTEGER)                .
                            .       .LE. NDLS                                   .
                            .    E2=PRESSURE AT FACE NODE N1                    .
                            .    E3=PRESSURE AT FACE NODE N2                    .
                            .    E4=PRESSURE AT FACE NODE N3                    .
                            .    E5=PRESSURE ATR  FACE NODE N4                  .
                            .IF LT .EQ. 2                                       .
                            .--SDSLDF(E1)=E2,E3,E4,E5,E6,E7,E8                  .
                            .  WHERE                                            .
                            .    E1=LOAD SET ID NUMBER (INTEGER)                .
                            .       .LE. NDLS                                   .
                            .    E2=WEIGHT DENSITY OF THE FLUID                 .
                            .    E3=X-ORDINATE OF POINT S IN THE FREE           .
                            .       SURFACE OF THE FLUID                        .
                            .    E4=Y-ORDINATE OF POINT S IN THE FREE           .
                            .       SURFACE OF THE FLUID                        .
                            .    E5=Z-ORDINATE OF POINT S IN THE FREE           .
                            .       SURFACE OF THE FLUID                        .
                            .    E6=X-ORDINATE OF A POINT N ON THE              .
                            .       NORMAL TO THE FLUID SURFACE                 .
                            .    E7=Y-ORDINATE OF A POINT N ON THE              .
                            .       NORMAL TO THE FLUID SURFACE                 .
                            .    E8=Z-ORDINATE OF A POINT N ON THE              .
                            .       NORMAL TO THE FLUID SURFACE                 .
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KEYWORD AND     NO.   TYPE  .  USAGE                                        . REF.
 TYPE OF        OF    OF    .                                               .
 ALLOCATION ENTRY ENTRY     .                                               .
---------------------------.-----------------------------------------------.--------
SDSLDI   SS     2   INTEGER.DISTRIBUTED SURFACE DATA                        .IV.8.9
                           .--SDSLDI(E1)=E2,E3                              .
                           .  WHERE                                         .
                           .     E1=LOAD SET ID NUMBER (INTEGER)            .
                           .        .LE. NDLS                               .
                           .     E2=ELEMENT FACE NUMBER ON WHICH THIS       .
                           .        DISTRIBUTED LOAD IS ACTING              .
                           .        E3=LOAD TYPE CODE                       .
                           .        .EQ. 1, PRESCRIBED NORMAL PRESSURE      .
                           .          INTENSITIES                           .
                           .        .EQ. 2, HYDROSTATICALLY VARYING         .
                           .          PRESSURE FIELD                        .
                           .        .EQ. 0, DEFAULT SET TO 1                .
SELCMP   NS     4   REAL   .SHELL ELEMENT LOAD CASE MULTIPLIERS             .IV.8.15
                           .--SELMCP=E1,E2,E3,E4                            .
                           .  WHERE                                         .
                           .     E1=FRACTION OF PRESSURE LOADS TO BE        .
                           .        APPLIED IN ELEMENT LOAD CASE A          .
                           .     E2=FRACTION OF PRESSURE LOADS TO BE        .
                           .        APPLIED IN ELEMENT LOAD CASE B          .
                           .     E3=FRACTION OF PRESSURE LOADS TO BE        .
                           .        APPLIED IN ELEMENT LOAD CASE C          .
                           .     E4=FRACTION OF PRESSURE LOADS TO BE        .
                           .        APPLIED IN ELEMENT LOAD CASE D          .
SELCMT   NS     4   REAL   .SHELL ELEMENT LOAD CASE MULTIPLIERS             .IV.8.15
                           .--SELCMT=E1,E2,E3,E4                            .
                           .  WHERE                                         .
                           .     E1=FRACTION OF THERMAL LOADS TO BE         .
                           .        APPLIED IN ELEMENT LOAD CASE A          .
                           .     E2=FRACTION OF THERMAL LOADS TO BE         .
                           .        APPLIED IN ELEMENT LOAD CASE B          .
                           .     E3=FRACTION OF THERMAL LOADS TO BE         .
                           .        APPLIED IN ELEMENT LOAD CASE C          .
                           .     E4=FRACTION OF THERMAL LOADS TO BE         .
                           .        APPLIED IN ELEMENT LOAD CASE D          .
SELCMX   NS     4   REAL   .SHELL ELEMENT LOAD CASE MULTIPLIER              .IV.8.13
                           .--SELCMX=E1,E2,E3,E4                            .
                           .  WHERE                                         .
                           .     E1=FRACTION OF X-DIRECTION GRAVITY TO BE.
                           .        APPLIED IN ELEMENT LOAD CASE A          .
                           .     E2=FRACTION OF X-DIRECTION GRAVITY TO BE.
                           .        APPLIED IN ELEMENT LOAD CASE B          .
                           .     E3=FRACTION OF X-DIRECTION GRAVITY TO BE.
                           .        APPLIED IN ELEMENT LOAD CASE C          .
                           .     E4=FRACTION OF X-DIRECTION GRAVITY TO BE.
                           .        APPLIED IN ELEMENT LOAD CASE            .
SELCMY   NS     4   REAL   .SHELL ELEMENT LOAD CASE MULTIPLIER              .IV.8.13
                           .--SELCMY=E1,E2,E3,E4                            .
                           .  WHERE                                         .
                           .     E1=FRACTION OF Y-DIRECTION GRAVITY TO BE.
                           .        APPLIED IN ELEMENT LOAD CASE A          .
                           .     E2=FRACTION OF Y-DIRECTION GRAVITY TO BE.
                           .        APPLIED IN ELEMENT LOAD CASE B          .
                           .     E3=FRACTION OF Y-DIRECTION GRAVITY TO BE.
                           .        APPLIED IN ELEMENT LOAD CASE C          .
                           .     E4=FRACTION OF Y-DIRECTION GRAVITY TO BE.
                           .        APPLIED IN ELEMENT LOAD CASE D          .
```

KEYWORD AND TYPE OF ALLOCATION		NO. OF ENTRY	TYPE OF ENTRY	USAGE	REF.
SELCMZ	NS	4	REAL	SHELL ELEMENT LOAD CASE MULTIPLIER --SELCMZ=E1,E2,E3,E4 WHERE E1=FRACTION OF Z-DIRECTION GRAVITY TO BE APPLIED IN ELEMENT LOAD CASE A E2=FRACTION OF Z-DIRECTION GRAVITY TO BE APPLIED IN ELEMENT LOAD CASE B E3=FRACTION OF Z-DIRECTION GRAVITY TO BE APPLIED IN ELEMENT LOAD CASE C E4=FRACTION OF Z-DIRECTION GRAVITY TO BE APPLIED IN ELEMENT LOAD CASE D	IV.8.13
SFTR	NS	1	REAL	SCALE FACTOR USED TO ADJUST THE DISPLACEMENT (OR ACCELERATION) ORDINATES IN THE SPECTRUM TABLE --SFTR=ENTRY	VII.24
SFTRS	NS	1	REAL	SCALE FACTOR USED TO ADJUST THE DISPLACEMENT (OR ACCELERATION) ORDINATES IN THE SPECTRUM TABLE --SFTRS=EN --SFTRS=ENTRY	VII.24
SHELL1	SS	5	INTEGER	SHELL DATA --SHELL1(E1)=E2,E3,E4,E5,E6 WHERE E1=ELEMENT NUMBER .LE. NSOL21 E2=NUMBER OF NODES TO BE USED IN DESCRIBING THE ELEMENT S DISPLACEMENT FIELD E3=NUMBER OF NODES TO BE USED IN THE DESCRIPTION OF ELEMENT GEOMETRY E4=MATERIAL IDENTIFICATION NUMBER .LE.NUMMAT E5=IDENTIFICATION NUMBER OF THE MATERIAL AXIS ORIENTATION SET .LE. NORTHO E6=IDENTIFICATION NUMBER OF THE STRESS OUTPUT SET .LE. NOPSET	IV.8.16
SHELL2	SS	8	INTEGER	SHELL DATA --SHELL2(E1)=E2,E3,E4,E5,E6,E7,E8,E9 WHERE E1=ELEMENT NUMBER E2=NODE NUMBER INCREMENT FORM ELEMENT DATA GENERATION E3=INTEGRATION ORDER FOR NATURAL COORDINATE (R,S) DIRECTIONS E4=INTEGRATION ORDER FOR NATURAL COORDINATE (T) DIRECTION E5=FLAG INDICATING THAT THE STIFFNESS AND MASS MATRICES FOR THIS ELEMENT ARE THE SAME AS THOSE FOR THE PRECEDING ELEMENT E6=PRESSURE SET FOR ELEMENT LOAD CASE A E7=PRESSURE SET FOR ELEMENT LOAD CASE B E8=PRESSURE SET FOR ELEMENT LOAD CASE C E9=PRESSURE SET FOR ELEMENT LOAD CASE D	IV.8.16

```
KEYWORD AND      NO.  TYPE  .  USAGE                                          . REF.
 TYPE OF         OF    OF   .                                                 .
  ALLOCATION ENTRY ENTRY    .                                                 .
----------------------------.-------------------------------------------------.--------
SMAOS       SS    3   INTEGER.SHELL MATERIAL AXES ORIENTATION SET             .IV.8.8
                            .--SMAOS(E1)=E2,E3,E4                             .
                            .  WHERE                                          .
                            .    E1=IDENTIFICATION NUMBER .LE.NORTHO          .
                            .    E2=NODE NUMBER FOR POINT I                   .
                            .    E3=NODE NIMBER FOR POINT J                   .
                            .    E4=NODE NUMBER FOR POINT K                   .
SSORLS      SS    7   INTEGER.SHELL STRESS OUTPUT REQUEST LOCATION SETS       .IV.8.13
                            .--SSORLS(E1)=E2,E3,E4,E5,E6,E7,E8                .
                            .  WHERE                                          .
                            .    E1=SET NUMBER .LE. NOPSET                    .
                            .    E2=LOCATION NUMBER OF OUTPUT POINT 1         .
                            .    E3=LOCATION NUMBER OF OUTPUT POINT 2         .
                            .    E4=LOCATION NUMBER OF OUTPUT POINT 3         .
                            .    E5=LOCATION NUMBER OF OUTPUT POINT 4         .
                            .    E6=LOCATION NUMBER OF OUTPUT POINT 5         .
                            .    E7=LOCATION NUMBER OF OUTPUT POINT 6         .
                            .    E8=LOCATION NUMBER OF OUTPUT POINT 7         .
SSPEC       SS    1   REAL  .VALUE OF DISPLACEMENT (OR ACCELERATION)          .VII.24
                            .FOR RESPONSE SPECTRUM ANALYSIS                   .
                            .--SSPEC(E1)=E2                                   .
                            .  WHERE                                          .
                            .    E1=DEFINITION POINT NUMBER .LE. NPTS         .
                            .    E2=ENTRY                                     .
S1TO8       SS    8   INTEGER.SHELL DATA                                      .IV.8.17
                            .--S1TO8(E1)=E2,E3,E4,E5,E6,E7,E8,E9              .
                            .  WHERE                                          .
                            .    E1=ELEMENT NUMBER .LE. NSOL21                .
                            .    E2=NODE 1 NUMBER                             .
                            .    E3=NODE 2 NUMBER                             .
                            .    E4=NODE 3 NUMBER                             .
                            .    E5=NODE 4 NUMBER                             .
                            .    E6=NODE 5 NUMBER                             .
                            .    E7=NODE 6 NUMBER                             .
                            .    E8=NODE 7 NUMBER                             .
                            .    E9=NODE 8 NUMBER                             .
S17TO21     SS    5   INTEGER.SHELL DATA                                      .IV.8.17
                            .--S17TO21(E1)=E2,E3,E4,E5,E6                     .
                            .  WHERE                                          .
                            .    E1=ELEMENT NUMBER .LE. NSOL21                .
                            .    E2=NODE 17 NUMBER                            .
                            .    E3=NODE 18 NUMBER                            .
                            .    E4=NODE 19 NUMBER                            .
                            .    E5=NODE 20 NUMBER                            .
                            .    E6=NODE 21 NUMBER                            .
S9TO16      SS    8   INTEGER.SHELL DATA                                      .IV.8.17
                            .--S9TO16(E1)=E2,E3,E4,E5,E6,E7,E8,E9             .
                            .  WHERE                                          .
                            .    E1=ELEMENT NUMBER .LE. NSOL21                .
                            .    E2=NODE 9 NUMBER                             .
                            .    E3=NODE 10 NUMBER                            .
                            .    E4=NODE 11 NUMBER                            .
                            .    E5=NODE 12 NUMBER                            .
                            .    E6=NODE 13 NUMBER                            .
                            .    E7=NODE 14 NUMBER                            .
                            .    E8=NODE 15 NUMBER                            .
                            .    E9=NODE 16 NUMBER                            .
```

KEYWORD AND	TYPE OF ALLOCATION	NO. OF ENTRY	TYPE OF ENTRY	USAGE	REF.
T	MS	1	REAL	TIME FUNCTION DEFINITION FOR RESPONSE HISTORY ANALYSIS --T(E1,E2)=E3 WHERE E1=TIME FUNCTION NUMBER (INTEGER) .LE. NFN E2=DEFINITION POINT NUMBER .LE. NLP E3=TIME VALUE	VII.14
TSPEC	SS	1	REAL	PERIOD (RECIPROCAL OF FREQUENCY) FOR RESPONSE SPECTRUM ANALYSIS --TSPEC(E1)=E2 WHERE E1=DEFINITION POINT NUMBER .LE.NPTS E2=PERIOD	VII.24
TZ	SS	1	REAL	SHELL DATA --TZ(E1)=E2 WHERE E1=ELEMENT NUMBER (INTEGER) .LE. NSOL21 E2=STRESS FREE REFERENCE TEMERATURE	IV.8.16
XYZT	SS	4	REAL	NODAL POINT DATA --XYZT(E1)=E2,E3,E4,E5 WHERE E1=NODAL POINT NUMBER .LE. NUMNP E2=X (OR R)-ORDINATE E3=Y -ORDINATE E4=Z (OR THETA)-ORDINATE E5=NODAL TEMPERATURE	III.1
WTDEN	SS	1	REAL	SHELL MATERIAL PROPERTY --WTDEN(E1)=E2 WHERE E1=MATERIAL ID NUMBER .LE. NUMMAT E2=WEIGTH DENSITY OF THE MATERIAL USED TO COMPUTE STATIC GRAVITY LOADS	IV.8.6

APPENDIX B

TIME HISTORY PLOT

The time history plot package is now an integral part of the SAP IV program. Response history analyses of displacements and stresses are produced for three element types - beams, thin plates, and thick shell (21 nodes). Analyses of other element types can be obtained but only a generalized labeling is available.

The plot package has been added to the SAP IV program with minimal modifications to SAP IV.

The input requirement for time history plot output is identical to the one for the response history analysis output request as given in the SAP IV manual, and no other input is required. However, the sequence of output for the time history plot is different from the arrangement of output for response history analysis output as indicated in the SAP IV manual. A maximum of three curves will be plotted within one frame for each node or element member.

APPENDIX C

MESH PROGRAM

PURPOSE

Program MESH produces undeflected mesh plots from data on TAPE 8 written by the SAP IV program. Using different input instructions, the entire element model, one part of the model, or a combination of different parts of the model may be plotted on one frame. Options of labeling all or selected nodes and/or elements are available. A unique line pattern represents each type of element--that is, a solid line for a beam element, a series of long dashed lines for a thin plate element and a series of short dashed lines for a thick shell element.

INPUT INSTRUCTIONS

Card one is required for the successful generation of one or more plots. Two additional cards are required for each plot to be generated.

Card One:

Col. 1-10	Vertical length of a plot in inches. Eight inches is used, allowing 1 inch for the legend at the bottom and a 7-inch square for the graphics. The positioning and sizing of all character symbols are fixed.
Col. 11-20	Scale factor. This allows the user to reduce or expand frame size with all proportions of the entire layout kept intact. It is defaulted to 1 if set blank.

Card Two:

This represents the first input card of each plot to be generated and is in free format. Keyword parameters available in the list below must be used.

X x-coordinate in cartesian system of viewer position

Y y-coordinate in cartesian system of viewer position

Z z-coordinate in cartesian system of viewer position

A All element members

B Beam element members

P Plate element members

S Shell element members

AN All element members with nodes labeled

BN Beam element members with nodes labeled

PN Plate element members with nodes labeled

BN Shell element members with nodes labeled

AE All element members with element labeled

BE Beam element member with element labeled

DE Plate element members with element labeled

SE Shell element members with element labeled

ANE All element members with nodes and elements labeled

BNE Beam element members with nodes and element labeled

SNE Shell element member with nodes and element labeled

The order and position of the keyword parameter is immaterial and is column independent on card. Each keyword parameter must be followed by a pair of parentheses, even though an entry is not required. Keyword parameter X, Y, and Z require the entry, if any, to be in floating point format--that is, it must have a decimal point. Entries for other parameters are to be in fixed point format or integer. Except for parameters X, Y, and Z, multiple entries are allowed and must be separated by a comma with no blank imbedded. The user can generate entries automatically between two given entries that are separated by one blank character. Samples are given below.

Card Three:

This represents the second input card of each plot and is used for repositioning of the plot pen for next plot or at the end of the plotting series.

Col. 1-10 +X - direction in inches

Col. 11-20 +Y - direction in inches

Sample 1

Graph size (vertical length) is 8 inches. Three plots are to be generated with the following input data. The first plot has all elements plotted with the viewer position at (1, 0,0) in cartesian space. The second plot uses a viewer position of (1, 1, 1) with all elements plotted and beam elements No. 1, 3, and 5 through 10 with nodes labeled. The third plot has the same viewer position as the second plot. In the third plot, beam elements 1 through 10 have nodes labeled, beam elements 8 through 15 have elements labeled, beam elements 16 through 20 have both nodes and elements labeled, and shell elements 1 through 10 have nodes labeled.

Card 1 $_{8}8._{11}$

Card 2 X(1.) A( )

Card 3 $_{7}10._{11}$ $_{18}0._{21}$

Card 4 X(1.) Y(1.) Z(1.) A( ) BN(1,3,5Ø10)

Card 5 $_{7}10._{11}$ $_{18}0._{21}$

Card 6 X(1.) Y(1.) Z(1.) BN(1Ø10) BE(8Ø15) BNE(16Ø20) SN(1Ø10)

Card 7 $_{7}10._{11}$ $_{18}0._{21}$

Card 8 7-8-9

Sample 2

Graph size (vertical length) is again 8 inches, but expanded by a factor of 2. A plot has all elements generated with nodes and elements labeled. Viewer position is (1, 1, 1) in cartesian space.

Card 1 $_{8}8._{11}$ $_{18}2._{21}$

Card 2 X(1.) Y(1.) Z(1.) ANE( )

Card 3 $_{7}10._{11}$

Card 4 7-8-9

APPENDIX D

CONTROL CARD SAMPLES

CREATE UPDATE FILE FOR FREE FORMAT INPUT PROGRAM,
SAP IV WITH TIME HISTORY PLOT PACKAGE, OR MESH
PROGRAM, AND SAVE ON PERMANENT FILE.

```
   JOB CARD with account number
   REQUEST (NEWPL,*PF)
   UPDATE (F,N)
   CATALOG (NEWPL, FFIPNEWPL, ID=)
(OR CATALOG, NEWPL, SAP4THNEWPL, ID= .)
(OR CATALOG, NEWPL, MESHNEWPL,ID=    .)
   7-8-9
   *DECK FFIP
(OR *DECK SAP4TH)
(OR *DECK MESH)
   -FORTRAN SOURCE PROGRAM
   6-7-8-9
```

COMPILE, CREATE BINARY OBJECT, AND SAVE ON
PERMANENT FILE.

```
    JOB CARD with account number
    ATTACH (OLDPL, FFIPNEWPL,ID=

(OR ATTACH, OLDPL, SAP4THNEWPL,ID= .)
(OR ATTACH, OLDPL, MESHNEWPL,ID=   .)
    UPDATE(F)
    REQUEST (LGO,*PF)
    FTN,A,I=COMPILE.
    CATALOG,LGO,FFIPLGO,ID =
(OR CATALOG, LGO, SAP4THLGO, ID=   .)
    7-8-9
    UPDATE DIRECTIVE
    6-7-8-9
```

EXECUTE FREE FORMAT INPUT PROGRAM, SAP IV WITH DATA
MODEX=1, AND MESH PROGRAM.

```
    JOB CARD WITH ACCOUNT NUMBER
    ATTACH FFIP,FFIPLGO,ID=
    LDSET,PRESET=ZERO
    FFIP.
    RETURN,FFIP.
    REWIND (TAPE1)
```

```
ATTACH, PLOT, PLOTLIBRARY, ID=CA.
ATTACH,SAP4, SAP4THLGO,ID .
LDSET, PRESET=ZERO, LIB=PLOT
SAP4(TAPE1)
RETURN,TAPE1,SAP4
REWIND(TAPE8)
ATTACH,MESH,MESHLGO,ID=
LDSET,PRESET=ZERO,LIB=PLOT
MESH.
RETURN,MESH,TAPE8.
REWIND,TAPE1.
ATTACH,CONVLGO,ID=CA.
CONVLGO.
ROUTE,TAPE2,DC=PR,FC=PL,EL=A6,IC=ASCII.
7-8-9
  FFIP INPUT DATA
7-8-9
  MESH INPUT DATA
6-7-8-9
```

END